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OXYGEN IN THE SUN.

By C. RUNGE and F. PASCHEN.

In the spectrum of a vacuum tube filled with oxygen Piazzi Smyth discovered a line of wave-length about 7775.[1] This line we have lately found to consist of three components, of which the strongest is the most refrangible and the weakest the least refrangible. They seem to coincide with three lines of the same relative intensities in the solar spectrum.

Oxygen vacuum tube	Mean error	Higgs' photographic atlas of the normal solar spectrum	REMARKS
7772.26	0.07	7772.20	Strongest line
7774.30	0.15	7774.43	
7775.97		7775.62	Weakest line

We had to use small dispersion for the sake of intensity and measured the middle of the two weaker lines with a wide slit, which did not separate them. Less weight must be given to their distance measured with a narrow slit, for with a narrow slit it was difficult to see them.

[1] PIAZZI SMYTH, *Trans. R. Soc. Edinburgh*, **32**, Part 3, 1883. No condenser or spark-gap must be interposed in the circuit.

The coincidence would not be convincing if there were many lines in this region of the solar spectrum. But as the following drawing shows, in which the solar spectrum is copied from Higgs' photographic atlas, there are very few lines in the neighborhood. Considering at the same time the accordance of the relative intensities there remains little doubt that the coincidences are real. In the more refrangible parts of the solar spectrum the lines are so closely set that the coincidences of the other oxygen lines with solar lines, which have been maintained by several authors, carry far less evidence.

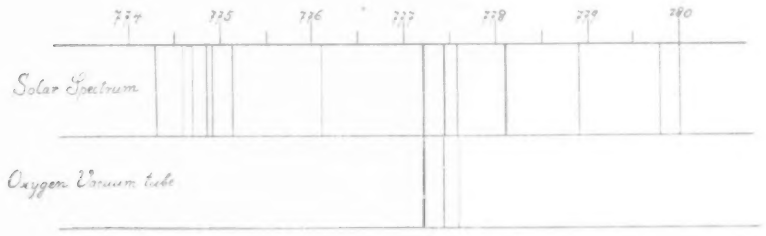


FIG. 1.

In order that the probability of a real coincidence remain the same, the accuracy should be proportional to the density of the lines.

If it could be shown that the three lines are not atmospheric lines, the presence of oxygen in the Sun would be proved. From general principles it may be said that an atmospheric origin seems improbable. For the spectrum of the oxygen vacuum tube differs widely from the absorption spectrum of atmospheric oxygen, as there is no trace of the bands A, B, etc., so prominent in the spectrum of the atmosphere.

The comparison of the spectra of high and low Sun is a better test. Mr. F. McClean has had the kindness to examine the appearance of the three lines on his negatives of the spectra of the high and low Sun. He thinks they do not depend on the elevation of the Sun above the horizon.

But there still remains a doubt. For if the lines originate in

the oxygen of the highest layers of the atmosphere, which for ought we know may have a spectrum different from that of the lower layers, high and low Sun might make little difference in the thickness of the layers traversed by the rays. A conclusive test of the true solar origin of the lines can only consist in a determination of their displacement on the Sun's limb. We hope that some one better equipped for this kind of work than we are will undertake to settle the question.

THE ALGOL VARIABLE + 17° 4367. W DELPHINI.

By EDWARD C. PICKERING.

AN ephemeris of the times of heliocentric minima of the Algol variable + 17° 4367 will be found in the ASTROPHYSICAL JOURNAL, **3**, 200. The formula employed is *J. D.* 2412002.500 + 4.8064 *E*. A continuation of this ephemeris is given below in Table I. for the year 1897. The form is slightly modified so that the number of the epoch is given in the first column, the Julian Day in the second column, omitting the constant number 2410000, the calendar date in the third column, and the Greenwich Mean Time expressed in hours and minutes in the fourth column. If the tenth of a minute is required it can be obtained from the second column.

TABLE I.

EPHEMERIS FOR 1897.

E.	J. D.	Date	G. M. T.	E.	J. D.	Date	G. M. T.
401	3929.8664	Jan. 4	$20^h\ 47^m$	423	4035.6072	Apr. 20	$14^h\ 34^m$
402	3934.6728	" 9	16 09	424	4040.4136	" 25	9 56
403	3939.4792	" 14	11 30	425	4045.2200	" 30	5 17
404	3944.2856	" 19	6 52	426	4050.0264	May 5	0 38
405	3949.0920	" 24	2 12	427	4054.8328	" 9	20 00
406	3953.8984	" 28	21 33	428	4059.6392	" 14	15 20
407	3958.7048	Feb. 2	16 55	429	4064.4456	" 19	10 42
408	3963.5112	" 7	12 16	430	4069.2520	" 24	6 03
409	3968.3176	" 12	19 38	431	4074.0584	" 29	1 24
410	3973.1240	" 17	2 58	432	4078.8648	June 2	20 45
411	3977.9304	" 21	22 19	433	4083.6712	" 7	16 06
412	3982.7368	" 26	17 41	434	4088.4776	" 12	11 28
413	3987.5432	Mar. 3	13 02	435	4093.2840	" 17	6 49
414	3992.3496	" 8	8 24	436	4098.0904	" 22	2 10
415	3997.1560	" 13	3 44	437	4102.8968	" 26	21 31
416	4001.9624	" 17	23 05	438	4107.7032	July 1	16 53
417	4006.7688	" 22	18 27	439	4112.5096	" 6	12 14
418	4011.5752	" 27	13 48	440	4117.3160	" 11	7 35
419	4016.3816	Apr. 1	9 10	441	4122.1224	" 16	2 56
420	4021.1880	" 6	4 31	442	4126.9288	" 20	22 18
421	4025.9944	" 10	23 52	443	4131.7352	" 25	17 38
422	4030.8008	" 15	19 13	444	4136.5416	" 30	13 00

TABLE I.—*Continued.*

EPHEMERIS FOR 1897.

E.	J. D.	Date	G. M. T.	E.	J. D.	Date	G. M. T.
445	4141.3480	Aug. 4	$8^h\ 21^m$	461	4218.2504	Oct. 20	$6^h\ 00^m$
446	4146.1544	" 9	3 42	462	4223.0568	" 25	1 22
447	4150.9608	" 13	23 04	463	4227.8632	" 29	20 43
448	4155.7672	" 18	18 25	464	4232.6696	Nov. 3	16 05
449	4160.5736	" 23	13 46	465	4237.4760	" 8	11 25
450	4165.3800	" 28	9 07	466	4242.2824	" 13	6 46
451	4170.1864	Sept. 2	4 28	467	4247.0888	" 18	2 08
452	4174.9928	" 6	23 50	468	4251.8952	" 22	21 29
453	4179.7992	" 11	19 10	469	4256.7016	" 27	16 51
454	4184.6056	" 16	14 32	470	4261.5080	Dec. 2	12 12
455	4189.4120	" 21	9 53	471	4266.3144	" 7	7 32
456	4194.2184	" 26	5 14	472	4271.1208	" 12	2 54
457	4199.0248	Oct. 1	0 36	473	4275.9272	" 16	22 15
458	4203.8312	" 5	19 57	474	4280.7336	" 21	17 37
459	4208.6376	" 10	15 19	475	4285.5400	" 26	12 57
460	4213.4440	" 15	10 40	476	4290.3464	" 31	8 18

For convenience of computation, it appears best for another year to use the same formula as in 1896. The observations indicate a slight change in the period so that the minima now occur about fifteen minutes before the times given in the ephemeris. A reduction of the observations already made will serve to determine the nature of these changes. They would be approximately represented by diminishing the assumed period, if it is constant, by about two seconds, and calling it 4.80638 instead of 4.8064. This difference was caused by our want of knowledge of the exact form of the light curve when the previous ephemeris was computed.

A correction for the equation of light may be computed by means of Table II., which gives for each tenth day the correction, expressed in seconds, to be added to the observed time to give the time of heliocentric minimum.

TABLE II.

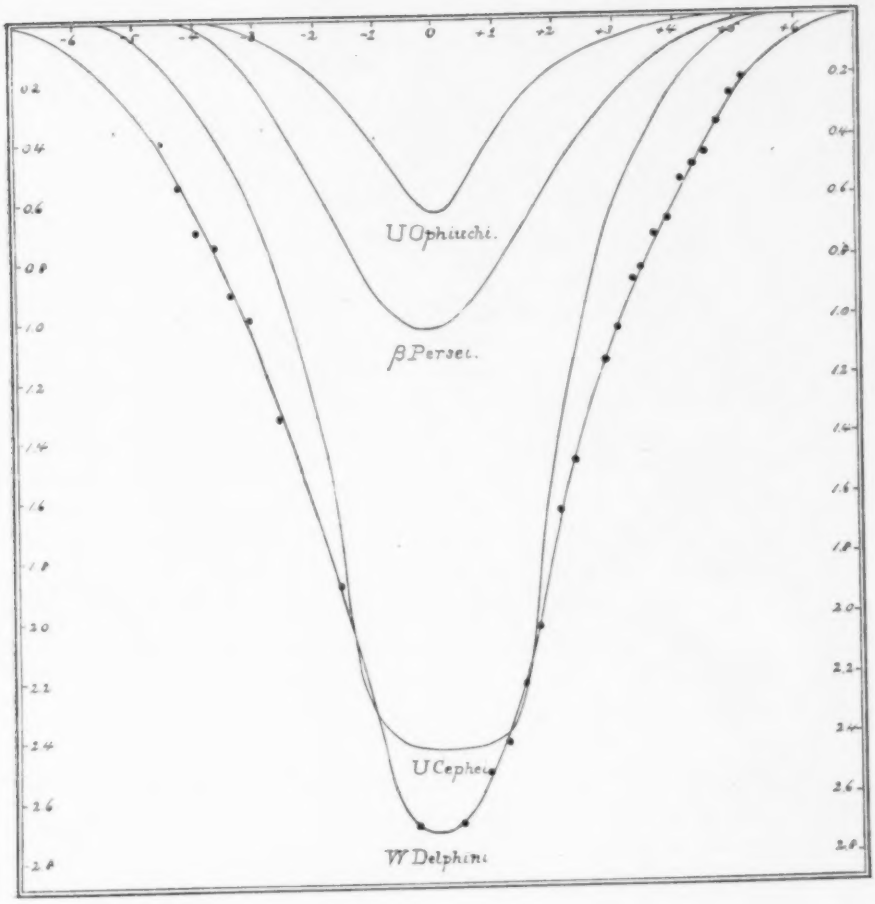
LIGHT EQUATION.

Date	Corr.	Date	Corr.	Date	Corr.
Jan. 0	−319^s	May 10	+ 18^s	Sept. 17	+325^s
" 10	−357	" 20	+ 87	" 27	+277
" 20	−383	" 30	+153	Oct. 7	+222
" 30	−398	June 9	+215	" 17	+159
Feb. 9	−401	" 19	+271	" 27	+ 92
" 19	−391	" 29	+319	Nov. 6	+ 22
Mar. 1	−369	July 9	+358	" 16	− 48
" 11	−336	" 19	+387	" 26	−117
" 21	−293	" 29	+405	Dec. 6	−183
" 31	−242	Aug. 8	+412	" 16	−243
Apr. 10	−183	" 18	+407	" 26	−295
" 20	−119	" 28	+391		
" 30	− 51	Sept. 7	+363		

Measures of the variable star were made with the meridian photometer on five nights, and gave the results 9.28, 9.34, 9.27, 9.35 and 9.11. The mean magnitude and average deviationare 9.27 ± 0.06. Similar measures of the adjacent star, $+17^\circ 4368$, gave 9.30 ± 0.05. These two stars have also been compared by Mr. O. C. Wendell with the photometer described in the ASTROPHYSICAL JOURNAL **2,** 1889, attached to the 15-inch equatorial. The total number of photometric settings exceeds four thousand. Measures of the full brightness on nine nights indicate that the first star was 0.10 fainter, instead of 0.03 brighter than the second. Combining the results of both photometers, its full brightness has been assumed to be 9.30. These observations also serve to determine the form of light curve whose coördinates are given in Table III.

The form of this light curve is also shown in Plate XIV., in which the earlier observed magnitudes, as determined with the photometer, are represented by dots and the light curve by a smooth line. The average deviation is between one and two-hundredths of a magnitude. The magnitude represented by each dot is in general derived from the mean of eighty photometric settings. The scale is such that five hours on the horizontal scale is represented by the same quantity as one

PLATE XIV.



LIGHT CURVES OF VARIABLE STARS.

magnitude on the vertical scale. Owing to the small number of observations where the star is very faint, there is still some uncertainty regarding the form of this portion of the curve.

TABLE III.

LIGHT CURVE.

Time	Magn.	Time	Magn.
$-7^h\ 00^m$	9.30	$0^h\ 00^m$	12.01
−6 30	9.34	+0 30	11.93
−6 00	9.42	+1 00	11.73
−5 30	9.50	+1 30	11.42
−5 00	9.60	+2 00	10.96
−4 30	9.77	+2 30	10.60
−4 00	9.96	+3 00	10.32
−3 30	10.17	+3 30	10.08
−3 00	10.41	+4 00	9.88
−2 30	10.70	+4 30	9.70
−2 00	11.01	+5 00	9.55
−1 30	11.34	+5 30	9.44
−1 00	11.69	+6 00	9.36
−0 30	11.97	+6 30	9.31
−0 00	12.01	+7 00	9.30

The light curves of three other variables of the Algol type, U Cephei, β Persei, and U Ophiuchi, have also been determined here photometrically. Their light curves are shown in the plate on the same scale as that of W Delphini. The variation of W Delphini amounts to 2.71 magnitudes, and is greater than that of any other star of this class. U Cephei is second with a variation of 2.44 magnitudes. The variations of β Persei and U Ophiuchi are 1.04 and 0.66 magnitudes respectively. The accuracy with which the form of the light curve can be determined is nearly proportional to the amount of the variation. The star W Delphini is therefore particularly interesting as a test of any theory relating to the dimensions and orbit of the eclipsing body.

HARVARD COLLEGE OBSERVATORY,
Cambridge, Mass., Nov. 6, 1896.

THE DETERMINATION OF THE RELATIVE QUANTITIES OF AQUEOUS VAPOR IN THE ATMOSPHERE BY MEANS OF THE ABSORPTION LINES OF THE SPECTRUM.[1]

By L. E. JEWELL.

THE investigation upon which the present report is based was begun by me, in accordance with the recommendation of Professor Henry A. Rowland, January 16, 1892.

In my preliminary report of June 1892, I expressed the belief that much more satisfactory results would be obtained if the investigation of the "rain band," which had then been carried on for about six months, were continued so as to include results for a whole year.

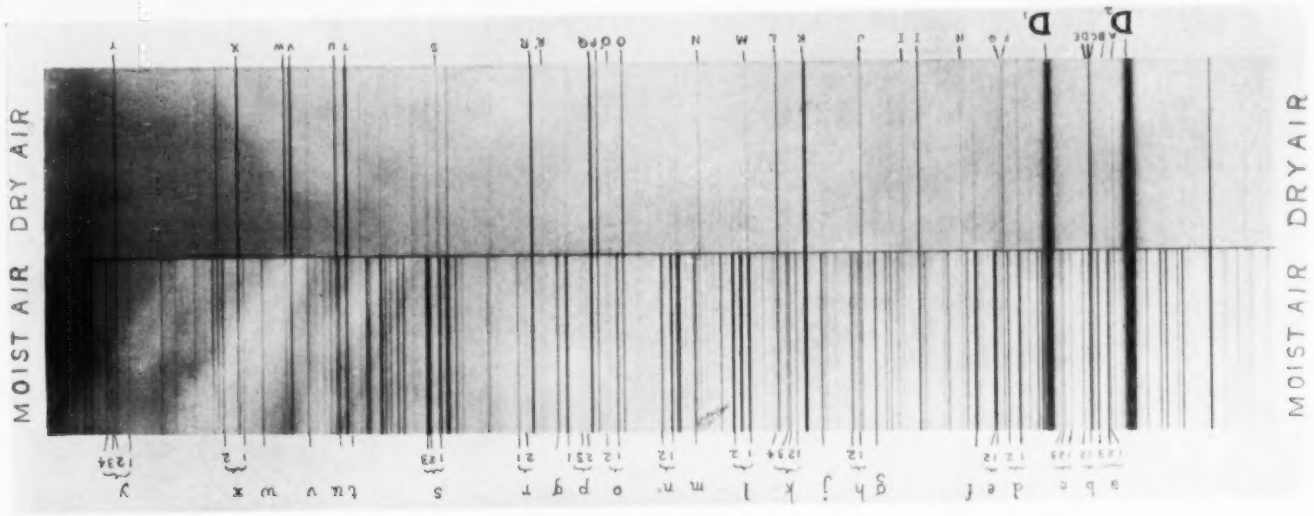
This has been done, and I now have observations from January 16, 1892, to July 31, 1893, inclusive. Those for the latter part of July and during the months of August and September, 1892, were made by Dr. C. P. Cronk and G. N. Wilson of the Baltimore station, U. S. Weather Bureau, to whom I am much indebted.

This report includes the results obtained for the period from January 16, 1892, to January 31, 1893; the observations from the latter date to July 31, 1893, not being as yet reduced.

Observations were made both by eye and by photographic means, but the latter method was soon discontinued as unsuitable for the purpose and dependence placed upon the eye observations alone. A photographic map of that portion of the solar spectrum from wave-lengths 5880 to 5950 was used for selecting a suitable series of solar and water-vapor lines for purposes of comparison (see Plate XV.). For convenience in references the solar lines used for comparison are marked A, B, C, D, etc. (with no reference to the Fraunhofer lines except D_1 and D_2); and the water-vapor lines are marked a, b, c, d, etc. The study

[1] Reprinted by permission from *Bulletin* No. 16 of the Weather Bureau, U. S. Department of Agriculture, with additions and corrections by the author.

PLATE XV.



WATER-VAPOR LINES IN THE SOLAR SPECTRUM.

was confined to this region because there were no entirely suitable photographs at hand of the rest of the rain band, though there are a number of lines in the rest of the band that would be of value in intensity comparisons, as also would be the series of water-vapor lines in the neighborhood of the hydrogen line C.

The method of observation used was to estimate the intensity of a water-vapor line in terms of the solar line most nearly equal to it in intensity, and in close enough proximity to render the comparison easy and sufficiently exact. One observation generally included several comparisons.

A more exact method would have been to make the observation when such a pair of lines (one solar and one water-vapor) were of equal intensity, as the eye is very reliable for such comparisons, but much less so in estimating differences of intensity. This, however, was impracticable under the circumstances, both because of the greater length of time it would require for observations, and because it would make necessary a more extensive series of comparison lines than had been selected in the region of the spectrum to which I had limited the work.

Having selected a series of comparison lines, it became necessary to determine the relative intensities of both the solar and the water-vapor lines used in the comparisons, in order that the observations might be available for actual measurements of intensity and might mean something really definite instead of merely guesswork. For this purpose a photographic scale was constructed, consisting of a series of lines regularly increasing in intensity from a line barely visible to others as strong as were desired.

A large, narrow slit was used, with a gaslight behind it and a plate of ground glass between them, to produce a more even light. A series of images of the slit were then made upon a photographic plate held in a camera, the lens of which had been covered with a piece of wire gauze, fine enough to produce a shading to the edge of the lines and a somewhat diffuse appearance of the lines themselves, but not sufficiently fine to produce any definite side lines due to diffraction fringes.

In the scale thus constructed the exposures were so timed as to be in geometrical ratio, the object being to form a scale of lines whose intensity should vary, as the geometrical series 1, 2, 4, 8, 16, etc. These lines formed the principal divisions, while, to facilitate measurements, an intermediate line was added by making the ratio of the series 1.414 or $1:\sqrt{2}$.

A fine-grained plate was used and so developed as to secure the best gradation and the clearest background obtainable. In this way a scale was produced, the lines of which closely resembled those in the spectrum of the earth's atmosphere and the better class of lines in the solar spectrum. The scale answered very well for preliminary work, but has several defects, which would be objectionable in more refined work. It is, however, possible to produce a photographic scale which will be entirely satisfactory. It is not true that a series of lines thus produced vary in intensity exactly as a geometrical series, but this is approximately true, and consequently such a scale possesses some of the advantages of a table of logarithms. By its use variations in the spectrum as a whole, such as are caused by the use of different gratings and different orders of spectra, with more or less diffuse light and different widths of slit, can be expressed by a constant, by the application of which observations made with different gratings under different circumstances can be reduced to standard conditions. This was shown experimentally, during the progress of this investigation, by the fact that measurements made in both the first and second order spectra of the grating used differed by a constant, and measurements of the different lines of the oxygen bands differed by constants, irrespective of the elevation of the Sun and the order of spectra or width of slit used. As a consequence of the properties of such a scale all necessary computations and reductions can be greatly simplified and shortened. The observations included in the scope of this paper have only been partly thus reduced, though had the method been extended much labor and time might have been saved.

In measuring the intensities of the solar lines the scale was

held in one hand and an eyepiece in the other, and the lines of the scale brought into focus with the solar line to be measured, the latter being brought into position between the two lines of the scale most nearly of the same intensity as the line to be measured. Holding the scale in the hand is not an ideal way of measuring and is not to be recommended, but it answered the purpose of a preliminary set of measurements, and there was no other convenient arrangement available. The relative intensities of the water-vapor lines should have been measured in this way, making several determinations with different degrees of humidity of the air, but this was not done, partly because of the lack of time required for making such measurements and partly because, under the conditions prevailing in Baltimore when the measurements were made, the conditions, otherwise favorable, occurred when the Sun was nearing the horizon and the intensities of the lines were changing too rapidly. Under these circumstances a much less desirable plan was adopted, viz., that of selecting those observations which included a comparison of both the lines to be measured and of the line taken as a standard (l_2) with solar lines, plotting the values thus obtained and deriving in this manner the relative values of the various water-vapor lines selected in terms of the one taken as standard. This plan is not to be recommended, but was the only one that seemed to be available.

In the same way the relation of eye-estimates of differences in intensity to scale values was determined by thus selecting observations which were considered most suitable for the purpose. The results were plotted and a curve drawn representing the relation of eye-estimates to scale values, and by which the differences in intensity as estimated by the eye were reduced to scale values, when the lines compared were not of equal intensity. This determination was not altogether satisfactory, but answered fairly well, as lines were generally selected for comparison which differed but little in intensity.

In Table II. are given the intensities of the solar lines used in terms of the standard line selected (Q) with their approximate wave-lengths.

In Table III. are given the water-vapor lines used, with their intensities in terms of the line selected as standard (l_2) and their approximate wave-lengths.

These values are not so accurate as might be desired, and are known to contain some errors, but on the whole they are fairly well determined, and I do not think it would be worth while to to make a redetermination by the same method.

Considerable trouble was occasioned by a few of the lines being partly solar and partly water-vapor, necessitating special observations to determine how much of the total intensity was due to each source.

Unfortunately, one of the most useful lines, and the one most used for low Sun observations, was found to be of this character. It is a double solar line at wave-length 5914.384, and has a water-vapor component coincident with the red component of the double.

Having finished the determination of the relative intensities of the lines selected and completed a series of observations, the results were put in tabular form and the reductions made as follows: The table (I,) begins with the date of the observation in the first column; then follows what may be called the astronomical data, viz., the time (T) according to eastern standard time; the hour angle (t), plus values representing values west of the meridian and minus values those to the east; the amplitude (A), reckoned from the south point, the signs being the same as for the hour angles; the apparent zenith distance (z), the correction for refraction having been made.

Then follows the amount (a) of atmosphere passed through by the sunlight at the given angle, and in the next column is given the factor (β) for reducing the intensities of the water-vapor lines as observed to what they would be were the Sun in the zenith. This factor is only approximate and varies according to the season, but only the mean value for each month is used.

Then follow the original observations upon the various water-vapor lines, given in terms of the solar line with which they were compared.

TABLE I.—*Original observations and reductions.*

(Extract from the complete table.)

Date	Time	Hour angle	Azimuth	Zenith distance	Amount of air traversed	Factor
1893	T	$h^t\ m$	$^\circ\ A\ '$	$^\circ\ z\ '$	a	β
Jan. 31	8.00 a. m.	.....	.....	.....	.....	.....
	9.45 a. m.	−2 35	−40 40	67 20	2.58	0.438
	12.30 p. m.	+0 10	+ 2 40	57 00	1.81	0.566
	3.00 p. m.	+2 40	+41 30	67 55	2.64	0.430
	4.57 p. m.	+4 37	+63 30	85 50	11.80	0.144
	8.00 p. m.	.....	.....	.....	.....	.....

Spectroscopic observations and results.

Intensities as originally observed				Intensities in terms of standard solar line (Q).				Intensities of standard water-vapor line (l).				Resulting intensities (l).	
l_2	n_1	o_1	p_1	l_2	n_1	o_1	p_1	l_2	n_1	o_1	p_1	Mean m	Reduced mean βm
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1.1*L*	.....	.....	0.9*O*	0.573	.....	.....	0.460	0.573	.....	.....	0.575	0.574	0.251
0.8*P*	2*N*	.....	.....	0.355	0.385	.....	.....	0.355	0.503	.....	.....	0.370	0.209
0.8*L*	.....	.....	0.8*O*	0.500	.....	.....	0.438	0.500	.....	.....	0.550	0.525	0.226
0.8*K*	.....	*R*	.....	(0.907)	.....	0.781	.....	1.650	.....	1.320	.....	1.450	0.209
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

Meteorological conditions.

Absolute humidity	Dew-point	Relative humidity	Temperature	Pressure	Rainfall
G. p. c. f.	° *F.*	%	° *F.*	*Inches*	*Inches*
1.745	27	70	35.6	30.245	Trace
.....	.....	.....	.....	.....	.....
.....	.....	.....	.....	.....	.....
.....	.....	.....	.....	.....	.....
.....	.....	.....	.....	.....	.....
1.892	29	75	35.0	30.325	0.00

The next series of columns give these values so reduced as to represent the intensity of the lines observed in terms of the standard solar line (Q).

In the next series of columns are the respective resulting values of the intensity of the standard water-vapor line (l_2) in terms of the standard solar line (Q).

Next is the column of means and then the reduced means giving the means multiplied by the reduction factor (β). This represents the value of the means reduced to what they would be were the Sun in the zenith.

Then follow the meteorological data, viz., the absolute humidity (h) or the amount of water-vapor contained in the air at the Baltimore station, given in grains per cubic foot; the dew point (*D. P.*); the relative humidity (*R. H.*); the temperature of the air (t); the height of the barometer (b), corrected and reduced to sea level; the precipitation (p) for the preceding twelve hours.

For comparison with meteorological data, the midday observation is much the most valuable, as the reduction to standard conditions (the conditions that would prevail were the Sun in the zenith) is less liable to error. Consequently pains were taken to secure as complete a set of midday observations as possible. In addition to these a set of observations at various altitudes of the Sun from noon to sunset were made every few days, in order that satisfactory curves for reducing observations to standard conditions might be constructed.

Considerable attention was also given to observations made upon the approach of both general and local storms and during the approach and prevalence of "cold waves." Observations were not confined to the water-vapor lines, but were occasionally made upon the various lines of oxygen, as it was desired to find the curve representing similar series of observations for one of the least changeable gases of the atmosphere. For this purpose oxygen lines were observed in the same manner as were the water-vapor lines, and, in addition, they were measured frequently by the scale, and the two methods were found to give the same results.

The observations were reduced and plotted and curves drawn representing approximately the mean monthly results. These monthly curves were used to reduce the observations to standard conditions. The daily curves differed considerably during the month, especially during spring and fall, but it was considered best for this investigation to only use a monthly mean curve.

In Table IV., the intensity of the standard water-vapor line at various altitudes of the Sun, during the different months of the year, is given as taken from the mean monthly curves referred to. In addition are given the intensities representing specially interesting conditions, viz., the readings from the curve of January 10, 1893, representing the curve for a "cold wave," and also the mean of the curves for July 14, 15, 16, 17, and 18, 1893, during the prevalence of warm, humid, weather conditions. In the same table are also given the results for oxygen. As this varies scarcely any during the year, a single curve suffices to represent it. The intensities given under oxygen are those of the first line in the tail of a (*i. e.*, the oxygen band a), in terms of the same standard solar line (Q) used for comparison with the water-vapor line.

A study of the values of the intensity curves, as given in Table IV., brings out some interesting results. Not only are the intensities for the summer months much greater than for the winter months, but the forms of the curves, or their slopes, are quite different and also decidedly different from the form of the curve representing oxygen, showing that the character of the distribution of water-vapor in our atmosphere is greatly different from that of oxygen and also greatly different at different seasons.

An interesting fact is the similarity in the curves for December, January, February, and March; the rapid change in the curves during April and the beginning of May; the gradual changes after August and during the fall months. The most remarkable difference, however, is between the conditions prevailing during cold waves and very warm, humid weather. The

distribution of water-vapor during cold waves seems to be much like that of oxygen, while during warm, humid weather it is almost entirely different.

In Table IV., the values given in parentheses are somewhat uncertain, observations not having been made at these altitudes; the horizon as seen from the heliostat of the spectroscope is clear only during part of the spring and winter, and the highest altitude of the Sun is at a considerable distance from the zenith during the winter.

As to the usefulness of the spectroscope in meteorological observations, my opinion is that for the study of the distribution of water-vapor in the atmosphere it is of great value, but as an instrument for regular observations upon which are to be based the predictions of future weather conditions, it is not much of an addition to the instruments already in use. It might be of considerable use at times, but hardly sufficient to justify its use at most meteorological stations. However, if a few selected stations were equipped with a simple form of instrument of sufficient dispersive power valuable data might be secured.

The increase in intensity of the water-vapor lines is quite decided upon the approach of a general storm, and depends to some extent upon the direction and the azimuth of the Sun, or the direction in which the instrument is pointed in relation to the position of the storm. There is much less of a change at the approach of a local storm, and if it be a small unimportant one, the strength of the water-vapor lines may scarcely be affected at all. Neither is there any perceptible increase in the intensity of these lines when the Sun is shining through clouds, or when the sunlight passes immediately underneath even a fairly large cumulus cloud. However, there is likely to be a marked diminution in the intensity of the water-vapor lines immediately after, even a small local storm, with an increase again to what it was before if the storm has been an unimportant one.

It may also be of interest to note the fact that there is a difference in the curves representing morning and afternoon observations, especially during the colder part of the year, the

slopes of the morning curve being steeper, and showing relatively less water-vapor in the lower region of the air than during the afternoon. In my opinion observations made with small spectroscopes having insufficient dispersion to easily see the various lines distinctly, are worse than useless, as the region of the rain-band contains many solar lines which cannot be distinguished from water-vapor lines without good definition and considerable dispersion.

The pointing of a spectroscope toward the sky, instead of the Sun, will also give erroneous results of scarcely any use whatever for purposes of study.

TABLE II. SOLAR LINES.

Name of line	Intensity Q = 1	Wave-length	Name of line	Intensity Q = 1	Wave-length
D_2	4.250	5890.186	L	0.551	5916.475
A*	*	5891.398	M	0.211	5918.773
B	0.072	5892.108	N	0.288	5922.334
C	0.183	5892.920	O	0.483	5928.013
D	0.755	5893.097	P	0.391	5929.898
E	0.060	5893.455	Q	1.000	5930.406
D_1	3.145	5896.154	R^1	0.137	5934.024
F	0.320	5899.518	R	0.781	5934.883
G	0.146	5899.752	S	0.195	5941.985
H	0.197	5902.694	T	0.935	5948.765
I	0.611	5905.895	U	0.355	5949.566
I^1	0.219	5907.060	V	0.680	5952.943
J	0.355	5910.197	W	0.319	5953.386
K*	*	5914.383	X	0.571	5956.923

$$A = 0.215\,Q + 0.135\,l_2$$
$$K = 1.280\,Q + 0.375\,l_2$$

* Intensities of solar lines having atmospheric components.

TABLE III. WATER-VAPOR LINES.

Name of line	Intensity $l_2 = 1$	Wave-length	Name of line	Intensity $l_2 = 1$	Wave-length
a_1	0.235	5891.720	k_4	0.205	5916.800
a_2	0.700	5891.878	l_1	0.425	5918.635
a_3*	*	5892.608	l_2	1.000	5919.860
b_1	0.300	5893.268	l_3	0.413	5920.776
b_2	0.355	5893.725	m	0.500	5922.735
c_1	0.250	5894.605	n_1	0.769	5924.490
c_2	0.270	5895.162	n_2	0.535	5925.220
c_3	0.200	5895.360	o_1	0.590	5928.510
d_1*	*	5898.378	o_2	0.132	5929.350
d_2	0.470	5899.215	o_3	0.085	5929.630
e_{1+2}	0.980		p_2	0.117	5930.815
e_1	0.410	5900.135	p_3	0.125	5931.230
e_2	0.620	5900.260	p_1	0.800	5932.306
f_1*	*	5901.682	q	0.400	5932.998
f_2	0.300	5902.363	r_2	0.135	5935.400
g	0.570	5909.213	r_1	0.295	5936.038
h_1	0.355	5910.398	s_1	0.550	5941.845
h_2	0.500	5910.987	s_2		5942.635
j	0.485	5913.212	s_3		5942.789
k_1	0.250	5915.146	t		5942.452
k_2	0.280	5915.650	u	0.635	5949.390
k_3	0.220	5915.840			

$$a_3 = 0.070\,Q + 0.410\,l_2$$
$$d_1 = 0.030\,Q + 0.840\,l_2$$
$$f_1 = 0.050\,Q + 0.950\,l_2$$

* Intensities of water-vapor lines having solar components.

TABLE IV.

MEAN INTENSITIES FROM CURVES REPRESENTING THE MEAN VALUES OF βm FOR THE RESPECTIVE MONTHS.

1892.

Zenith distance of Sun		January	February	March	April	May	June
	0°	(0.150)	(0.200)	(0.210)	(0.300)	0.460	0.650
	30	(0.200)	(0.250)	0.275	0.370	0.570	0.860
	50	0.250	0.320	0.325	0.490	0.800	1.300
	70	0.420	0.510	0.500	0.800	1.530	2.430
	80	0.770	0.830	0.790	1.330	2.450	3.650
	85	1.130	1.270	1.170	1.950	3.330	(4.650)
	87 30′	1.490	1.780	1.560	2.530	(4.050)	(5.250)
	89	(1.930)	2.500	2.080	(3.050)	(4.800)	(5.700)
	90	(2.550)	(3.400)	(2.900)	(3.600)	(5.900)	(6.200)
Amount of water (thickness of equivalent layer in inches) held in suspension in the form of water-vapor,		0.670	0.900	0.950	1.370	2.120	3.050

Zenith distance of Sun		July	August	September	October	November	December
	0°	0.560	0.500	(0.320)	(0.340)	(0.260)	(0.180)
	30	0.730	0.670	0.420	(0.440)	(0.340)	(0.230)
	50	1.080	0.950	0.670	0.550	0.440	0.300
	70	2.000	1.600	1.470	1.000	0.770	0.580
	80	3.130	(2.500)	2.380	1.740	1.440	1.080
	85	(4.320)	.....	3.250	2.580	2.160	1.620
	87 30′	(5.200)	.....	(4.000)	3.500	2.870	2.100
	89	(6.000)	.....	.....	(4.300)	3.550	2.700
	90	(6.500)	.....	.....	(5.200)	(4.500)	(3.700)
Amount of water		2.600	2.310	1.460	1.560	1.180	0.810

TABLE IV.—*Continued.*

1893.

Zenith distance of Sun		January	February	March	April	May	June	July
	0°	(0.160)	(0.180)	(0.230)	0.320	0.400	0.600	0.580
	30	(0.205)	(0.240)	0.300	0.390	0.490	0.760	0.705
	50	0.260	0.310	0.350	0.500	0.640	1.140	0.970
	70	0.410	0.440	0.530	0.960	1.180	1.920	1.770
	80	0.730	0.700	0.920	1.480	2.030	2.700	2.490
	85	1.120	1.070	1.350	(2.000)	2.950	(3.400)	3.010
	87 30′	1.550	1.450	1.720	(2.470)	(3.600)	.....	(3.600)
	89	2.060	1.860	2.030	.....	.....	.....	.....
	90	(2.750)	2.600	2.700	.....	.....	.....	.....
Amount of water	.....	0.710	0.810	1.040	1.460	1.850	2.790	2.700

INTENSITIES FROM CURVES REPRESENTING SPECIAL CASES.

Zenith distance of Sun		Cold-wave, January 10, 1893	Warm-wave, July 15, 16, 17, and 18, 1893		Oxygen (1st line in tail of α, wave-length = 6287.953)
	0°	(0.080)	1.000		0.240
	30	(0.110)	1.270		0.270
	50	0.140	1.670		0.330
	70	0.201	2.750		0.430
	80	0.310	3.600		0.610
	85	0.485	(4.600)		0.900
	87 30′	0.680	.....		1.200
	89	0.930	.....		1.550
	90	(1.300)	.....		2.000
Amount of water	.....	0.355	4.830		.....

At the request of Dr. J. S. Ames, the following notes have been added to the above paper on "The Determination of the Relative Quantities of Aqueous Vapor in the Atmosphere, by means of the Absorption Lines of the Spectrum," reprinted from Bulletin No. 16, of the Weather Bureau, Department of Agriculture.

In the original paper it was thought best to confine all remarks to the results obtained. In the following notes a brief statement will be given of the results which in my judgment the spectroscopic method is capable of giv-

ing if investigations are carried out along certain lines to which attention will be called.

The basis of all future observational work having for its object the spectroscopic solution of any meteorological problems must be an intensity scale, by means of which the relative intensities of atmospheric lines can be determined with a reasonable degree of accuracy. In the paper referred to is described the photographic scale used in that investigation. As stated there, it was only a provisional scale containing several defects. One can be made, however, which will perfectly answer the purpose, and it is expected that this will be done shortly.

The lines of such a scale should resemble as closely as possible the lines in the spectrum of the Earth's atmosphere, of which the lines in the absorption spectrum of oxygen are the best by which to gauge such a scale.

Without going into the subject exhaustively it may be said that the increase in darkness, or intensity of absorption, from the edge to center of the lines of the scale should be as nearly as possible the same as that of the lines in the absorption spectrum of oxygen. The lines composed should also be of the same width as the oxygen lines in the particular spectroscope used.

A curve representing this change in intensity from margin to center may be called the intensity curve of the line, and can best be reproduced thus: make an aperture of the form of this curve and place an evenly illuminated source of light behind it, draw a small image of this aperture into a line (by using a cylindrical lens) and photograph it. Thus a photographic line can be made which shall resemble as closely as we please the atmospheric lines of the spectrum.

Now as the Sun decreases in altitude and its light passes through increasing thicknesses of absorbing gases in our air, the atmospheric lines increase in both intensity (or darkness) and breadth.

The whole breadth of a line may be considered to be made up of an infinite number of elements, whose varying intensity of absorption gives the line its peculiar character or intensity curve. The central elements have the greatest and the marginal the weakest power of absorption and as the light passes through increasing quantities of the air, the intensity of absorption of each element will increase according to a perfectly definite law of absorption. The change in intensity of the entire line will depend upon the change of the intensity of absorption of each element from the margin to the center as well as the actual value of the absorption of each element for a given amount of the absorbing media.

With the lines of the photographic scale the same thing holds true. If the intensity curve be the same, and for a certain amount of silver deposited the photographed line matches the atmospheric line both in intensity, width,

and appearance when both are brought into focus together, then if the amount of silver deposited in the scale line and the amount of absorbing media the sunlight passes through be increased or diminished in the same ratio, the two lines will still match or remain of the same intensity and appearance.

If the silver deposited varied directly as the exposure, then the photographic scale would be a quantitative scale for measuring atmospheric lines, as the intensities would vary precisely alike in the two cases.

The deposit of silver varies nearly as the exposure within certain limits, but gradually changes as the exposure is increased. Such being the case, the scale made by increasing the exposure according to a definite ratio will not form an exact quantitative scale; but fortunately it can be calibrated either by measuring the increase of scale intensity by a very delicate photometer or a bolometer; but a much better plan in practice is to calibrate it by direct comparisons in the spectroscope with the lines of atmospheric oxygen.

This operation can be performed by any good observer with a spectroscope of sufficient power, wherever he may be. The first line in the tail of the α group ($\lambda = 6287.953$) should be taken as the standard, when the Sun is in the zenith, the observer at sea level and the barometer standing at 760^{mm}. Comparisons can be made with this standard line at various altitudes of the Sun, and the amount of oxygen passed through by the sunlight can be found by the tables of Forbes and Bouguer, and thus the quantitative values of the scale be determined, or it can be compared with other oxygen lines whose relative intensities have been determined.

A scale such as has been described will fit accurately only that spectrum and grating for which it was made and calibrated, but if the exposures used in making the lines of the scale varied according to geometrical ratio, then the differences of measures made in this particular spectrum and any other will be constant, and as this constant can be applied to measurements they can be readily reduced to standard conditions.

Probably because of conditions as regards temperature prevailing in the solar atmosphere, the true solar lines in the spectrum are not as dark as the lines produced by the gases in the Earth's atmosphere; but by the use of a little judgment the relative intensities of solar lines can be measured quite satisfactorily so that they can be used as standards of reference. The intensities given in Tables II. and III. were made with a scale in some ways defective, and it is important that the lines should be carefully remeasured, particularly those of Table III., which are most in error. It is hoped that this can be done before long.

Numerous observations made upon the various lines of the oxygen bands δ, α, B, and A, have shown that the intensity curve of all of these lines is either exactly the same or very nearly so, unless the line is a double or mixed in some way with other lines. It is so nearly true, that the curves

representing the intensities of the lines in the various oxygen bands for various altitudes of the Sun can be reduced to each other by the application of a reducing factor, although the actual intensities of the different lines vary enormously.

Also if two well-determined points be taken upon the curve and the value of the absorption factor be thus determined, a complete curve can be formed theoretically which will fit into the curve representing actual observations within the limits of the errors of observation.

The above facts would indicate that within the limits of variation of pressure to which the oxygen of the atmosphere is subjected, there is no appreciable change in the form of what has been called the intensity curve of absorption lines. It is known, however, that when the pressure is greatly increased beyond one atmosphere the form of this curve is considerably changed, being considerably flattened as the lines are broadened by increasing pressure.

I have dwelt at length upon the case of oxygen because it has an important bearing upon that of water-vapor.

The law governing the distribution of oxygen in the air is quite well known and the variations to which it is subjected are comparatively slight, and hardly great enough to perceptibly influence the appearance of lines in the absorption spectrum of oxygen, or at least any change will be very small. As a consequence, spectroscopic observations can be compared with known data and the dependence of the varying intensity of the absorption lines upon the variation of the amount of oxygen passed through by the sunlight, determined directly and accurately.

The case of water-vapor is essentially different. The amount of it present in the air is extremely variable with changes in the season and considerably so from day to day. It must also vary greatly for different latitudes and even for different places having the same latitude.

Moreover, the distribution of water-vapor in the atmosphere is practically unknown. Of course some work along this line has been done at mountain observatories and by the aid of baloons and kites, but the results are meager and unsatisfactory. Furthermore, the conditions prevailing at mountain observatories are probably far from being the same as at the same elevation in the air away from the influence of the mountain.

The question that forces itself upon one is: Cannot this problem be attacked spectroscopically? Most assuredly it can, but there are difficulties in the way.

Much time and work has been spent upon this problem but the solution has not yet been obtained because of the lack of necessary and vital data. I have attempted to supply the missing data indirectly but the result is uncertain and therefore unsatisfactory.

Before the problem can be solved, it will be necessary to first construct a more satisfactory photographic scale than the one heretofore used for measurements, and then to determine the intensity of several water-vapor lines after passing through known quantities of water-vapor.

The only satisfactory and the easiest method of securing this data will be to compare the intensities of water-vapor lines when the Sun is nearly overhead and the spectrum obtained directly, with the intensity of the same lines when the sunlight has been caused to pass through a few miles of water-vapor near the Earth's surface. This can be done by placing at a station, a few miles distant, mirrors and a lens so mounted that a strong beam of sunlight can be sent from the station to the heliostat mirror of the spectroscope. The distant station selected should have nearly the same altitude as the observing station, and preferably the country between should be comparatively level and the height of both stations above the surrounding country small.

Observations should be made upon several days having a considerable range of humidity, but unsettled weather should be avoided if possible. Hygrometric observations should be made at both stations, and if convenient at one or more intermediate places, during the progress of the work. In making the spectroscopic observations the width of the slit should remain unchanged and the direct sunlight weakened so as to correspond with the reflected light. Observations should be made by comparing the water-vapor lines with solar lines of the same intensity but the main dependence should be placed upon the scale measurements, and as a check it will be well to measure both some solar and oxygen lines.

Having secured satisfactory measurements made upon days having as wide a range of humidity as necessary for the purpose, we can determine the change in the intensity of water-vapor lines produced by known amounts of water-vapor, and consequently the amount required to produce any given intensity of a line. This will give the quantitative values of the different intensities of the lines in the absorption spectrum of water-vapor; and what has been termed the intensity curve of the lines may be determined. Incidently the photographic scale may be standardized for water-vapor as for oxygen.

Probably all of the single lines of water-vapor will have the same intensity curve, but whether this is so or not can be determined by the use of a good scale. Observations under various conditions for two years indicate that it is true, but it should be tested more carefully with a more satisfactory scale than I used. The intensity curve will be very much like that for the oxygen lines but my investigations, so far, indicate that there is certainly a difference, the slope of the curve being rather steeper. The question as to there being any possible changes in the form of this curve due to considerable differ-

ences in density of the water-vapor in our atmosphere is somewhat difficult to answer. It can be investigated, but the investigation is somewhat difficult.

Probably if a set of measurements such as has been referred to be made with quite a large range in the hygrometric conditions the effect of density can be determined, if there is any appreciable effect in the limited range of pressures we are likely to meet in the air. The problem can also be studied by indirect methods but not so satisfactorily. The correct way, however, would be to have two reflecting stations, one of which is considerably farther away than the other, and make a set of observations with light reflected from both; but probably one station with observations made under a sufficiently wide range of hygrometric conditions will give entirely satisfactory data.

The results obtained from oxygen, however, would indicate that at the vapor pressures which we are likely to meet with in the air there would be little if any perceptible change in the form of the intensity curve, though probably great changes would occur if the pressure were increased greatly beyond atmospheric pressure.

Having obtained the data referred to we would be in a position to determine, approximately at least, by making a series of observations during the day from noon to sunset, together with a set made in the morning, not only the total amount of water-vapor held in suspension in the air during the day but also the distribution of the water-vapor at different heights above the Earth's surface, or the hygrometric gradient for altitude.

This cannot be determined directly but must be solved indirectly. Several of the most probable values of the hygrometric gradient for altitude can be used and theoretical curves constructed which would represent the intensities of water-vapor lines for different altitudes of the Sun, based upon these values. These theoretical curves can then be compared with the curves representing actual observations, and in this manner a series of typical curves can be constructed theoretically, which will fit the various curves representing spectroscopic observations; and when this is carefully done, both the hygrometric gradient and the actual amount of water vapor at any given height in the air can be determined. Of course the results will not be as accurate as thermometrical or barometrical observations, but will be approximately correct and give a good idea of the hygrometric conditions prevailing at different altitudes. Local irregularities, however, will be difficult to recognize, the results representing the gradual changes with elevation in which local irregularities are ignored for the most part at least, but this is what we most need in meteorological studies. For this reason, spectroscopic observations are more useful for determining the conditions prevailing at different seasons and studying seasonal changes, than for determining the conditions prevailing during any particular day. They are also very valuable for studying the conditions prevailing with special types of weather, such as cold waves, continued hot, humid, summer weather, or warm waves, and also the approach

of extensive storms. The differences in the form of the curves representing these special types are very marked indeed, as is also the difference between the spring and fall months.

It is hardly necessary to say that if the missing data can be supplied and observations made at some of the more important places in different latitudes, results of the greatest value in meteorological study can be obtained; the expense attending such investigations would be exceedingly small when compared with investigations made from baloons or by the aid of kites, and the results obtained would probably be more satisfactory in many ways.

A good grating having large dispersion is absolutely necessary, but an elaborate or expensive mounting is not. Observations made with small instruments, particularly with pocket direct vision spectroscopes are worse than useless, especially if the instrument be pointed to the sky instead of the Sun.

A point of considerable interest in connection with observations made to determine the hygrometric gradient for the air, is that if this be determined satisfactorily and clouds at different heights have been present during the day, and we know fairly well the heights of these clouds, the temperature gradient for altitude can be determined approximately. The amount of moisture being known for a given height at which precipitation is occurring, and consequently the air saturated with moisture, the temperature can be determined approximately. Determinations of this kind, however, being only roughly approximate, are better suited for giving general results or a good idea of the gradient and seasonal changes than for an individual determination for any particular date.

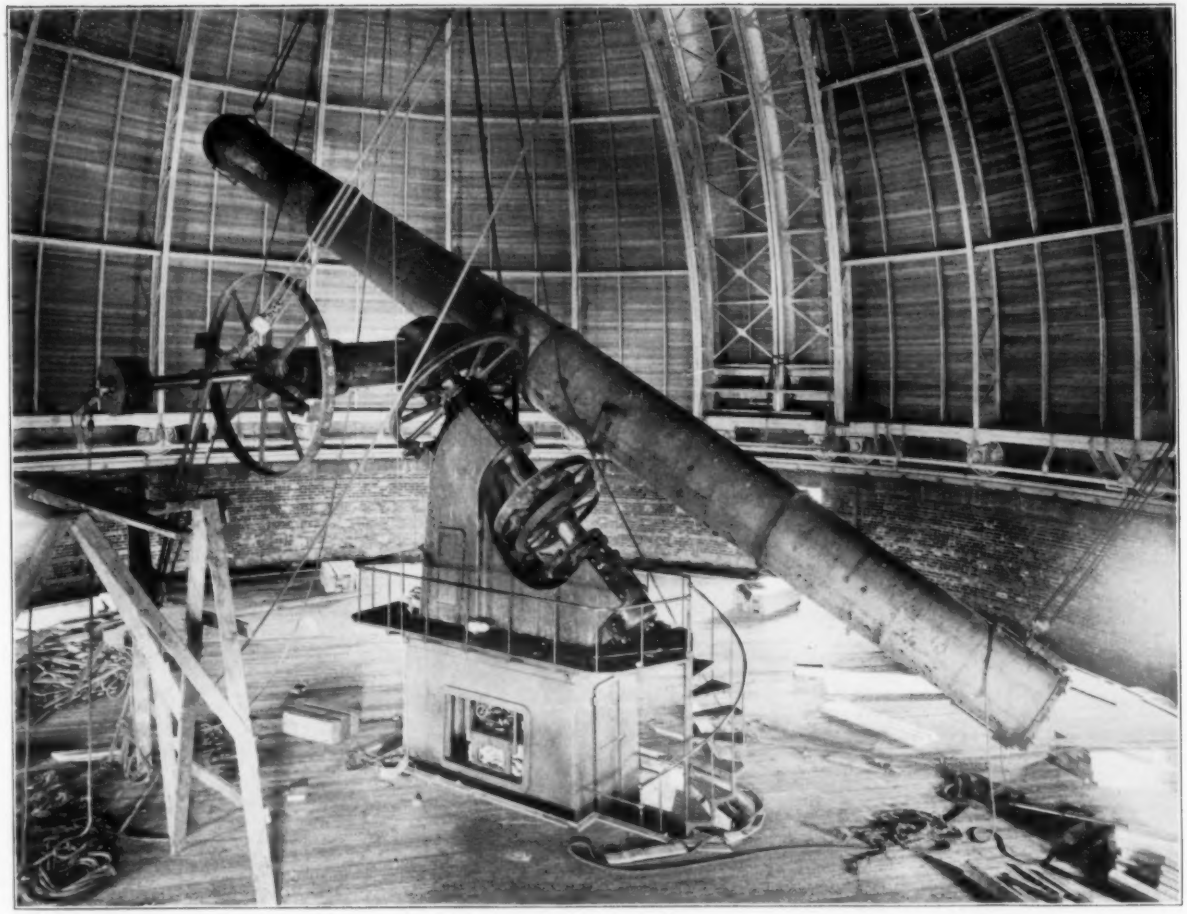
If the missing data can be obtained, the observations made during 1892 and 1893 can be used for determining the total moisture held in suspension in the air throughout the year, and also the hygrometric gradient for altitude; if used together with the observations of clouds made at the Baltimore and Washington stations of the United States Weather Bureau, a rough approximation to the temperature gradient for altitude with the seasonal changes can be obtained.

The approximate values for the total amount of moisture held in suspension during the different months, have been determined by an indirect method and are given at the bottom of Table IV.; but the values are somewhat uncertain and may be either greater or smaller than given. The estimates are probably something like the true values, and the relative values are rather accurate.

Tables II., III., and IV. differ somewhat from the tables as published by the Weather Bureau in being more complete, and Table IV. is here given for nearly nineteen months instead of one year only.

JOHNS HOPKINS UNIVERSITY,
November 1896.

PLATE XVI.



MOUNTING OF THE 40-INCH YERKES TELESCOPE.

NOVEMBER 1896.

The rising-floor is shown at its highest level.

RESEARCHES ON THE ARC-SPECTRA OF THE METALS. III. COBALT AND NICKEL. II.[1]

By B. HASSELBERG.

COBALT AND OTHER METALS PREVIOUSLY INVESTIGATED BY KAYSER AND RUNGE.

IN making these comparisons I have merely used the corresponding tables of wave-lengths, without taking photographs containing the spectra of the two elements in question. The results showed at once that the metals indium, thallium, lead, arsenic, antimony, bismuth, and cadmium have not a single coincidence with cobalt, while potassium, sodium, lithium, cæsium, rubidium, magnesium, tin, and mercury have a few more or less close coincidences, the accidental character of which, however, could not be open to doubt. Similar approximate coincidences between lines of cobalt and of the metals of the alkaline earths are also found, as may be seen in the following table, in which Kayser and Runge's wave-lengths are given, with the uncertainty to which they are subject and other remarks of the authors. These remarks are sufficient to indicate the wholly accidental character of the coincidences.

Co	Ca		
4092.98	92.92	± 0.10	Diff. toward red.
4581.71	81.66	0.10	
4624.70	24.70	0.50	Diff. toward red.

Co	Sr		
3504.81	04.70	± 0.30	Very diffuse.
4607.46	07.52	0.03	Not sharp.
4869.59	69.41	0.10	Diffuse.
4968.09	68.11	0.03	

[1] Continued from p. 304.

The rising floor is shown at its highest level.

Co	Ba		
3562.22	62.28	± 0.10	Diffuse.
77.80	77.79	0.05	Diffuse.
3910.08	10.04	0.05	Not sharp.
75.47	75.55	0.10	Diff. toward red.
4179.38	79.57	0.20	Diff. toward red.
5381.30	81.25	0.50	Diff. toward red.

The only line in the above list which, in case of exact coincidence, might possibly be foreign to cobalt, is the line λ 4607.46, since the corresponding strontium line is the very strongest in the spectrum of that metal. But the absence of any trace of the other chief lines of strontium, as well as the still existing uncertainty of the coincidence, seem to justify its retention in the spectrum of cobalt. As for calcium, several of the principal lines occur regularly on my plates; but they are immediately recognizable as foreign lines by the fact that they only appear as fine points at the borders of the spectrum, which is possible only when the vapor producing them is in the immediate vicinity of the electrodes. That these lines belong to calcium is apparent from the following comparison with the corresponding wave-lengths of Kayser and Runge's catalogue.

Co		Ca	
λ	i	λ	i
4226.90	2	26.91	6
83.15	2	83.16	5
89 55	1.2	89.51	5
99.10	1.2	99.14	4
4302.65	2.3	02.68	6
18.86	1.2	18.80	5
4425.60	1.2	25.61	6
35.10	2	35.13	6
35.90	1.2	35.86	5
55.00	2.3	54.97	6

Since electrodes made of electrolytically deposited copper instead of carbon were used in photographing the violet and ultra-violet spectrum, in order to avoid the carbon bands which appear in these regions, there remain to be eliminated only the

copper lines which are produced by this method. These lines are fortunately not very numerous, and, with a few easily recognized exceptions, so weak and diffuse that any connection between them and lines of cobalt having nearly the same positions can hardly be assumed. In the following list, obtained by comparison with Kayser and Runge's investigation of the copper spectrum, those lines are shown which have nearly identical positions in the two spectra:

Co λ	i	Cu λ	i	Remarks
3520.20	3	20.13 ± 0.05	3	Diffuse.
3613.90	1.2	13.92 0.05	2	Diffuse.
20.58	2	20.53 0.05	2	Diffuse.
24.47	2	24.41 0.05	2	Diffuse.
41.95	2.3	41.85 0.05	2	Diffuse.
45.36	2	45.38 0.05	2	Diffuse.
52.68	2.3	52.62 0.15	1	Very diffuse.
54.59	2	54.6 0.50	2	Very diffuse.
3734.30	2	34.33 0.05	2	Diffuse.
41.40	1	41.38 0.05	3	Diffuse.
4011.07	1	11.02 0.20	2	Very diffuse.
4275.29	1	75.38 0.05	5	
4531.14	5	31.10 0.10	5	Diffuse.
87.08	1.2	87.25 0.15	6	
4651.28	1.2	51.37 0.10	5	
5105.73	2	05.81 0.05	5	
53.43	1.2	53.29 0.20	5	Very diffuse.
58.61	2	58.59 0.15	1	Diffuse.
5218.42	2	18.52 0.10	6	Diffuse.

This table may be divided into two parts. The second part, beginning with the line λ 4275, was derived from photographs taken with carbon electrodes, while for the first part electrodes of copper were used. Now in the second part there are cobalt lines which nearly coincide with the strongest copper lines, and it might therefore be doubted whether these lines belong to the cobalt spectrum. If they are regarded as actually belonging to copper, then either the electrodes or the cobalt must have contained copper as an impurity. The former assumption is negatived by the fact that no trace of these lines is found on the plates of the nickel spectrum, which were obtained with elec-

trodes of the same manufacture. The nickel itself is also shown to be free from these lines, and the existence of the copper in the cobalt is thereby rendered improbable. At present, therefore, I am disposed to regard the close coincidence as accidental, especially since, on the one hand, the uncertainty of Kayser and Runge's wave-lengths does not allow a final decision as to coincidence or non-coincidence to be made, and, on the other hand, the diffuseness of the copper lines gives them a character entirely different from that of the sharp lines of cobalt. As for the lines in the first part of the table, the probability of coincidence, when the smaller uncertainty of the wave-lengths in the copper spectrum is taken into account, is somewhat greater; but in consideration of the fact that all the copper lines are weak and diffuse, the cobalt lines, on the contrary, strong and sharp, a real connection between them can hardly be assumed. This mode of regarding the question finds support in the circumstance that if it were incorrect, the same lines must appear in the corresponding parts of the spectrum of nickel, as these were also obtained with copper electrodes; this, however, is not the case.

COMPARISON OF THE NICKEL SPECTRUM WITH PREVIOUSLY KNOWN SPECTRA OF OTHER METALS.

NICKEL AND IRON.

Although, as in the case of cobalt, the iron lines on the plates were sifted out as carefully as possible in the first examination of the photographs of the nickel spectrum, a subsequent comparison with Kayser and Runge's catalogue of iron lines yielded a very considerable number of approximate coincidences, which made necessary a more thorough investigation with the aid of plates containing the spectra of both substances. The result is shown in the following table:

Ni λ	Ni i	Fe λ	Fe i	Remarks
3458.59	4	58.61	2	Coinc. Belong to Ni.
61.78	4	61.79	2	
62.95	1	62.93	1	Fe missing.
72.68	3.4	72.67	1	Fe missing. Belongs to Ni.
74.21	1.2	74.20	1	Fe missing. Belongs to Co, Mn.
76.19	1.2	76.23	1	Fe missing.
78.04	1	77.99	2	Very weak. Coinc.?
83.93	3	83.97	1	Fe missing. Belongs to Cu.
89.59	1	89.55	1	Fe missing. Belongs to Co.
93.10	4.5	93.10	2	Coinc. Belongs to Ni.
3502.44	1.2	02.41	1	Fe missing. Belongs to Co.
06.47	1.2	06.45	1	Fe missing. Belongs to Co.
10.47	4	10.49	1	Trace of Fe. Belongs to Ni.
12.78	1	12.84	1	Fe missing. Belongs to Co.
15.17	4.5	15.21	2	Coinc. Belongs to Ni.
18.80	2	18.86	1	Fe missing.
24.65	5	24.68	2	Coinc. Belongs to Ni.
29.93	1.2	29.96	3	Coinc. Belongs to Co.
30.51	2	30.54	2	Coinc. Belongs to Ti.
53.63	2	53.64	1	Fe missing.
66.50	4.5	66.52	2	Coinc. Belongs to Ni.
75.52	1.2	75.55	3	Coinc. Belongs to Co.
87.32	1.2	87.40	1	Divided. Belongs to Co.
97.84	3.4	97.90	1	Trace of Fe. Coinc.
99.27	2	99.18	1	Coinc. λ Fe = 99.28? Also Co.
3613.90	1.2	13.81	1	Divided.
27.93	1	27.97	1	Fe missing. Belongs to Co.
64.24	3	64.16	1	Divided.
69.38	2	69.35	2	Fe missing.
3739.36	2.3	39.28	1	Divided.
49.15	2	49.12	2	Divided, λ Ni > λ Fe.
3845.58	2.3	45.64	1	Trace of Fe, Coinc. Belongs to Co.
76.96	1.2	76.87	1	Divided. Belongs to Co.
94.20	2.3	94.15	2	Divided. The lines do not belong to Ni and Fe, but to Co and Cr.
3905.67	1.2	05.70	1	Fe missing.
10.07	1.2	10.01	3	Divided, λ Ni > λ Fe.
58.35	1	58.35	1	Missing.
66.20	1	66.22	3	Coinc. Belongs to Fe.
66.78	1	66.76	3	Coinc. Belongs to Fe.
70.65	2	70.57	3	Divided, λ Ni > λ Fe.
74.83	2	74.87	1	Divided, λ Ni < λ Fe.
81.90	1	81.93	4	Probably divided. Int. Ni = 2. Belongs to Ti.
84.18	2	84.14	1	Divided, λ Ni > λ Fe.
89.90	1	90.00	2	Divided, λ Ni < λ Fe. Int. Ni = 2.
95.45	3.4	95.40	1	Divided, λ Ni > λ Fe.
98.77	1.2	98.82	1	Fe missing. Int. Ni > 1.2.
4010.14	1.2	10.11	1	Fe doubtful.
18.24	1	18.27	1	Coinc. Belongs to Mn.
19.20	1.2	19.19	1	Coinc.?
41.52	2	41.50	3	Coinc. Belongs to Mn.
48.87	1	48.88	2	Coinc. Belongs to Mn.
55.68	1.2	55.69	3	Coinc. Belongs to Mn.

Ni λ	Ni i	Fe λ	Fe i	Remarks
4057.45	1	57.49	3	Divided, λ Ni < λ Fe.
58.36	1	58.36	3	Belongs to Co, Fe.
58.91	1	58.92	3	Coinc. Belongs to Fe, Cr.
59.07	1	59.06	1	Coinc. Belongs to Mn.
64.55	2	64.61	2	Divided, λ Ni < λ Fe.
92.55	2	92.48	3	Belongs to Ni.
4121.48	3	21.54	1	Fe missing.
23.96	1	23.87	3	Divided, λ Ni > λ Fe.
42.34	1	42.37	1	Fe missing.
50.55	1.2	50.48	3	Divided, λ Ni > λ Fe.
95.71	2.3	95.77	2	Divided, λ Ni < λ Fe.
4252.25	1	52.33	1	
4436.52	1	36.51	1	Belongs to Mn.
37.17	2.3	37.10	2	Divided, λ Ni > λ Fe.
42.61	2	42.52	5	Divided, λ Ni > λ Fe.
50.44	1	50.50	2	Missing.
51.72	1.2	51.77	2	Coinc. Belongs to Mn.
4534.21	1	34.19	1	Belongs to Co.
47.15	3	47.20	3	Divided, λ Ni < λ Fe.
65.78	1.2	65.87	2	Divided, λ Ni < λ Fe.
80.77	1.2	80.73	2	Coinc.
81.79	1	81.72	3	Divided. The line under Ni belongs to Co.
96.11	2	96.20	2	Divided.
4606.37	2.3	06.40	1	Fe missing.
4712.24	1	12.27	1	Fe doubtful.
52.58	2	52.56	1	Fe missing.
83.53	1	83.62	3	Divided, λ Ni < λ Fe. The Fe line belongs to Mn.
99.98	1	4800.04	1	Divided, λ Ni < λ Fe.
4832.86	1.2	32.90	2	Divided, λ Ni < λ Fe.
38.80	2	38.72	1	Divided, λ Ni > Fe.
43.27	1	43.37	2	Coinc. λ Fe apparently in error by 0.10.
4937.51	2	37.50	1	Fe missing.
97.04	1	97.06	1	
5012.62	2	12.56	1	
18.50	2	18.59	3	Divided, λ Ni < λ Fe.
51.74	1	51 78	4	Divided, λ Ni < λ Fe.
84.27	4	84.32	1	Fe missing.
97.06	2	97.13	3	Divided, λ Ni < λ Fe.
5100.13	3.4	00.06	1	Fe missing.
21.74	1.2	21.77	2	Divided, λ Ni < λ Fe.
25.39	2.3	25.33	5	Divided, λ Ni > λ Fe.
42.96	3.4	43.05	3	Divided.
46.64	4	46.63	1	Fe missing.
86.80	1	86.71	1	Fe missing.
5218.41	1	18.36	2	Belongs to Co.
5371.64	2.3	71.68	6	Divided, λ Fe > λ Ni.
5504.50	1.2	04.57	1	
5637.32	2	37.35	1	Fe missing.
49.90	2.3	49.96	1	
95.22	3	95.27	1	
5712.10	3	12.08	2	Only a trace of Fe.
15.31	3	15.30	3	Fe extremely faint.
82.34	1	82.34	5	Fe missing.

The same conditions are seen here as in the case of cobalt. We find, namely, that a considerable number (about a third) of the approximate coincidences recorded above consist of pairs of lines, the components of which are distinctly separated, although by only a very small interval, while the iron lines corresponding to the other two-thirds are not found on my plates. The origin of the remaining pairs for which coincidence is assured can in several cases be ascribed with certainty to foreign metals (manganese), and these metals therefore exist as impurities in the nickel used by me, and in the iron used by Kayser and Runge. Setting these lines aside, there remains only a comparatively small number of doubtful cases, the lines being as follows:

λ	i	
	Ni	Fe
3478.04	1	2
3958.35	1	1
4010.14	1.2	1
4019.20	1.2	1
4252.25	1	1
4580.77	1.2	1.2

That the first elimination of the iron lines was a very complete one is apparent in the fact that there are only two lines in the table of which it can safely be asserted that they belong to iron and not to nickel. These are the lines λ 3966.20 and λ 3966.78. On the other hand the line λ 5732.84 is certainly not iron, notwithstanding its great intensity as observed by Kayser and Runge, since it neither appears on my plates nor was it found in iron by Rowland. On account of its feeble intensity in the nickel spectrum I have stricken it from the list of nickel lines, as very probably due to an impurity. As for the line λ 5715.31, which it is perfectly certain occurs also in titanium, a judgment founded on Kayser and Runge's value for the intensity must ascribe it also to iron; but the extreme faintness of the line on my plates causes me to feel doubtful of this.

NICKEL AND TITANIUM.

For a comparison of the spectra of these two metals I may refer to my investigation of the titanium spectrum; with respect to

NICKEL AND MANGANESE

an examination of the plates containing both spectra gives the results exhibited in the following table:

Ni λ	Ni i	Mn λ	Mn i	Belongs to	Remarks	
3474.21	1.2	74.20	2.3	Co	Intensity variable in Mn.	74.20
3548.34	2.3	48.35	2.3	Ni, Mn	Coincident.	
69.51	1.2	69.51	4		Divided, λ Mn > λ Ni. The line under Ni belongs to Co.	
99.27	2	99.30	1	Ni, Co		
3619.52	5	19.42	3		Divided.	19.60
70.57	2.3	70.67	1.2		Divided.	
3729.05	1	29.05	2		Divided, λ Ni > λ Mn.	
36.94	3.4	37.03	1.2		Divided, λ Mn > λ Ni.	
3823.65	1.2	23.64	4	Mn, Cr		23.72
38.42	3	38.41	3.4	Mg	Coin. Int. Ni variable.	
45.58	2.3	45.58	1.2	Co		45.64
73.25	2.2	73.23	1.2	Co		
74.08	2	74.08	1.2	Co		
94.20	2.3	94.21	1.2	Co		94.15
3953.07	2	53.00	2		Divided, λ Ni > λ Mn.	
84.18	2	84.31	1		Divided, λ Mn > λ Ni.	84.14
87.26	1	87.23	2	Mn		
95.45	3.4	95.45	1	Ni, Co		95.40
4018.24	1	18.25	3.4	Mn		18.27
41.52	2	41.49	5	Mn		41.50
48.87	1	48.88	4	Mn		48.88
55.68	1.2	55.68	4.5	Mn		55.69
58.07	1	58.10	2.3	Mn		
59.07	1	59.08	3.4	Mn		59.05
92.55	2	92.55	1.2	Co		92.49
4131.33	1	31.26	2.3	Mn		
49.00	1	48.95	2.3	Mn		
4201.88	2.3	01.88	2		Divided, λ Mn > λ Ni.	
35.30	1	35.28	3	Mn		
35.46	1	35.45	3	Mn		35.47
84.20	1	84.22	2.3	Mn		84.26
4436.52	1	36.52	3	Mn		36.56
51.73	1.2	51.75	3.4	Mn		51.77
55.48	1	55.50	3	Mn		
4783.53	1	83.60	5	Mn		83.62
4823.67	1	23.71	5	Mn	Coinc.	23.69
5017.75	3.4	17.78	2		Probably divided, λ Mn > λ Ni.	
5197.40	1	97.44	1		Coinc.	
5388.71	1	88.76	1.2		Divided.	
5504.50	1.2	04.53	1.2		Divided, λ Ni < λ Mn.	

It is apparent that in almost all cases in which the lines are not divided or are to be ascribed to cobalt, they belong to manganese. They are for the most part the same lines which were recognized as impurities in photographing the cobalt spectrum. As entirely foreign is to be regarded the line λ 3838.42, which appears with different intensities on various plates of the nickel spectrum, and which certainly therefore does not belong to nickel. If this line has a constant intensity in the manganese spectrum it probably belongs to manganese as well as to magnesium.

NICKEL AND CHROMIUM.

Beside those lines which were found in the investigation of chromium, and which cannot be divided from the nickel lines having nearly identical positions, I have found on repeating the examination the following pairs, the origins of which must for the present remain undecided.

Ni		Cr	
λ	i	λ	i
3683.65	1	83.60	1.2
88.58	2.3	88.56	1.2
3730.88	1.2	30.91	2
3994.13	2	94.10	1.2
4046.91	1	46.89	1
75.05	1.2	75.01	1.2
4284.83	2.3	84.84	1.2
4383.05	1	83.04	1.2
4490.71	2	90.70	1.2

The two lines λ 3688.58 and λ 4284.83 must probably, if the coincidence is exact, be removed from the chromium spectrum; there appears however to be a slight difference of position, at least with respect to the latter line, since the nickel line is very slightly more refrangible than the chromium line.

NICKEL AND OTHER METALS.

In comparing the spectrum of nickel with that of other metals investigated by Kayser and Runge, I have found only the following few cases of coincidences in which the approximation corresponds to the probable error of measurement:

NICKEL λ	i	OTHER METALS λ	i	
3832.44	2.3	32.46 ±0.03	6	Mg
3683.65	1	83.63	5	Pb
5504.50	1.2	04.48 0.05	6	Sr
3577.37	1	77.45 0.10	1	Sr
3610.60	4	10.66 0.03	6	Cd
5709.80	3.4	09.82 0.15	2.3	Ba
5424.85	2	24.82 0.05	5	Ba
4605.15	4	05.11 0.05	2	Ba

The agreement of these positions must, considering the limits of accuracy given by Kayser and Runge for their wave-lengths, be regarded as exact. Nevertheless, the coincidences are quite certainly accidental, partly because no other lines of these metals are found in the nickel spectrum, and partly because the lines have often a totally different character. The lines of nickel are all sharp, while those of the other metals are diffuse, and even unsymmetrically diffuse. We have therefore in the above table an additional illustration of the fact that two different metals may emit rays of so nearly identical periods that they cannot be separately distinguished without a materially greater precision of measurement than that which it has been possible to attain in this investigation.

With the entire remaining series of metallic spectra investigated by Kayser and Runge, the spectrum of nickel either has no connection whatever, or, when an isolated case of coincidence occurs, no doubt can be felt as to its accidental character in view of the reasoning above given, and when the considerable uncertainty of some of Kayser and Runge's measures is taken into account.

After this explanation I give in the following table the wave-lengths of the lines which may be ascribed to these two metals. The arrangement of the catalogue is the same as that previously adopted, and it therefore requires no further explanation. With reference to the last column, however, it may be noted that the earlier measures of Thalén and Liveing and Dewar are there given, reduced to the wave-length system of Rowland.

SPECTRUM OF COBALT.

Cobalt λ	R.	i Co	i ⊙	Remarks	Liveing and Dewar
3471.52		2.3	3	⊙ double? { 71.47 Fe .52 Co	
74.15		4	3	Diffuse; reversed; ⊙ double? violet component = Co	73.95
74.66		2	1	⊙ double.	
76.49		2	2		76.55
78.01		1.2	1.2		
78.69		2	2	}	78.55
78.90		2	1.2	}	
80.16		1.2	—		
83.55		3	2	Reversed.	83.25
85.49		3.4	2.3	Also an important Fe line.	85.25
87.86		2	1	Near 87.82 Ca (according to K.-R.).	
89.54		4	2.3	Reversed.	89.36
90.89		2.3	?		
91.46		2.3	2.3		91.16
——	3491.46				
92.15		1.2	1.2		
95.82		3.4	2.3		95.66
96.83		3	2	Reversed. ⊙ double.	96.56
3502.41		4.5	3	Diffuse; reversed.	02.16
02.76		3	2.3	Diffuse; reversed.	02.56
03.86		1.2	1		03.96
04.88		2	?		
05.28		1.2	—		
06.44		4	3	Diffuse reversed.	06 16
09.98		3.4	2	⊙ double; divided from 10.01 Fe	09.86
10.53		3.4	3	⊙ double? Co = red component.	10.26
12.78		3.4	2.3		12.56
13.62		3.4	2.3		
3518.49		3.4	2.3		18.26
——	3518.49				
19.90		2	3	Ni, Co?	
20.20		3	3		20.06
21.70		3	2.3	Reversed.	21.46
23.00		2	2	Divided from 23.03 Fe.	
23.57		3	2	Reversed; ⊙ double { 23.47 .57 Co	23.46
23.85		2.3	1.2		
25.97		1.2	2		
26.96		4.5	2.3	Diffuse; reversed.	26.86
29.17		3	2		28.96
29.92		4.5	3	Diffuse; reversed; also a weak Fe line.	29.87
33.49		3.4	1	Reversed.	33.37
34.92		2	?		
43.40		3	1.2	Very sharp.	43.37
——	3545.33				
46.86		2	1		
48.60		2.3	1		48.57
50.72		3	2	Reversed.	50.67
52.85		2	1	} ⊙ triple { 52.85 Co .98 Fe	52.97
53.12		2.3	1	} { 53.12 Co	

Cobalt λ	R.	i Co	i ⊙	Remarks	Liveing and Dewar
3552.28		1.2	1		
58.90		2.3	2	Very sharp.	
60.44		2	—		
61.01		3	2	Reversed.	61.07
62.22		2.3	1	Very sharp.	
63.04		2.3	1	Very sharp.	
64.25		2	2		
65.08		3	2	Reversed.	65.07
68.36		1.2	2		
69.48		5	2	Very diffuse ; reversed.	69.47
——	3570.22				
75.06		3	2	Diffuse ; reversed.	75.07
75.48		3.4	2	Diffuse ; reversed.	75.47
77.36		1.2	1.2	Ni, Co?	
77.80		1.2	?		
78.20		2	1		77.98
79.01		2	?		
79.16		2	?		
82.00		2	?		
84.92		2.3	1.2	Very sharp.	
85.28		3.4	2	Reversed.	85.28
85.92		1.2	?	Divided from 85.90 Fe	
86.20		1.2	?	⊙ double? { 86.20 Co / .30 Fe	
87.30		5	3.4	Diffuse ; reversed.	87.28
89.41		1	—		
91.92		1.2	1		
95.00		3.4	2	Reversed.	94.98
96.67		2	1		
——	3597.10				
3600.99		1.2	—		
04.62		2	1		
05.19		2	1		
05.50		3	3	⊙ double? { 05.50 Co / .62 Fe	05.58
08.50		1.2	—	Divided from 08.55 Mn	
09.92		1.2	1		
11.89		2.3	1.2		11.88
——	3612.22				
15.56		2	1		15.38
18.17		1.2	?		
20.59		2	2		
24.48		2	2		
25.13		2.3	1		
27 96		3.4	2		27.88
31.55		3	—		
32.12		2	—		
33.00		2.3	1.2		32.78
33.52		1.2	?	Sharp.	
34.86		2.3	2		34.78
36.89		2	2	Very sharp.	36.68
37.49		2	—	Very sharp; divided from 37.45 Fe	

Cobalt λ	R.	i Co	i ⊙	Remarks	Liveing and Dewar
3639.63		2.3	1.2	⊙ line probably double.	39.48
——	3640.54				
41.95		2.3	1.2		41.68
43.34		2.3	—	On the edge of the ⊙ line 43.30.	43.28
45.36		2	—		
45.60		1.2	?		
47.25		2	1		
47.82		2.3	?		
48.30		2	?		
49.47		3	2.3	Also an unimportant Fe line.	49.38
51.42		2	—	Very sharp.	
52.68		2.3	2		
54.59		2	1	Very sharp.	54.58
57.12		2	1	Sharp.	56.68
58.05		1.2	2	Also a weak Fe line.	
62.33		—	—	Divided from 62.37 Ti.	62.38
——	3667.40				
70.20		1.2	2		
76.69		3	1.2		
83.18		3.4	2.3	Also Fe.	83.09
84.62		2.3	1		
85.13		1.2	—		
86.63		1.2	—		
90.87		2	2	Very sharp.	90.79
93.27		2.3	—		92.99
93.53		1.2	1		
93.65		2.3	2	Sharp. Divided from 93.70 Mn.	93.39
——	3695.19				
3702.40		2.3	2		02.30
04.17		3	2.3		04.10
07.61		2	1.2	⊙ double { 07.60 Co. 07.70 Ti.	
08.96		2.3	1.2		
11.80		1.2	1		
12.31		2	1		12.20
26.80		1.2	1		
30.61		2.3	2	⊙ close triple { 30.43 Fe. .50 Fe. .60 Co.	33.40[1]
31.42		1	1		
——	3732.54				
32.52		3	2.3	Also Fe.	
33.62		2.3	1.2		33.40
34.30		2.3	1.2	Sharp Cu has 34.33, but the line is diffuse and weak.	
36.05		2.3	1.2		35.80
40.31		2	?		
45.61		3.4	?		46.40
50.06		2.3	1		
51.75		2	1.2		
52.95		1	—		
54.50		1.2	—	Sharp.	

[1] Sic. 31.40? Eds.

Cobalt λ	R.	i Co	i ⊙	Remarks	Liveing and Dewar
3755.59		2.3	1	Sharp.	54.50
—	3756.21				
59.83		1.2	—		
60.52		1.2	—		
74.72		2	?	Divided from 74.75 (Mn ?)	74.60
77.65		2	—		77.60
—	3783.67				
3805.90		1.2	1		
08.24		2	1.2		07.91
11.16		1.2	1.2		
12.57		1.2	1		
14.58		2	—		
16.46		2.3	2		15.72
16 58		2.3	1		16.31
17.02		2	?	Does not coincide with ⊙ 17.05.	
18.08		1.2	?		
20.02		2	?		
33.02		1.2	1.2		
35.82		1.?	?		
36.04		1.2	—		
41.60		2	1	Sharp.	
42.20		3.4	2	Diffuse.	42.02
—	3843.41				
43.90		2	2		
45.59		4.5	2.3	Diffuse. Reversed.	45.42
50.24		1.2	?		
51.09		2.3	—	Very diffuse. Perhaps a weak ⊙ line, close to the strong line 51.00 (Fe).	
51.97		2	1		
56.93		2	—	Very sharp.	
60.55		2	1	Also Mn.	
61.29		3	?		61.12
63.72		1.2	2		
66.92		1	1.2		
70.65		2	1.2	Sharp.	
73.25		4.5	2.3	Diffuse. Reversed.	73.02
74.10		3.4	2.3	Diffuse.	73.82
—	3875.22				
76.99		3	2		76.72
80.54		1.2	2		
81.18		1.2	2		
82.04		3.4	2.3	⊙ probably double { 82.04 Co. .12.	81.63
84.76		2.3	2	Very sharp.	84.63
85.40		2	2.3	Very sharp. ⊙ perhaps double. Co represents violet component. Red component stronger, = Fe, Cr.	
91.83		1.2	—		
92.25		1.2	—		
93.19		1	1.2	Sharp.	
93.44		1.2	—		
94.21		5	2	Diffuse. Reversed. Cr has 94.20 (3), perhaps divided.	94 03

Cobalt λ	R.	i Co	i ⊙	Remarks	Liveing and Dewar
3895.12		3.4	2		94.93
——	3897.60				
98.64		2	1	⊙ double { 98.55 .65 Co.	
3904.20		2	1		
06.42		3	2		05.83
10.08		3.4	2.3	⊙ close double { 09.98 Fe. 10.08 Co.	09.63
15.66		1	1		
——	3916.88				
17.26		2.3	—	⊙ 17.30 (Fe).	16.83
19.79		1.2	—		
20.28		2	?		
20.89		2	1.2	Very sharp ⊙ triple { 20.75 Fe. .89 Co. .99 Fe.	
21.24		1.2	?		
22.88		2.3	2	Very sharp.	
25.32		1.2	—		
29.42		2	?	Between a fine ⊙ line and a double. Coinc.?	
33.32		1	?		
34.05		2	1.2		
36.12		4	2	⊙ { 35.95 Fe. 36.12 Co.	36.13
——	3937.47				
41.01		2.3	2.3	Also Fe.	
3941.87		3	2		41.53
45.47		3	2		45.53
47.28		1.2	1		
52.47		2	?		
53.05		3.4	2.3		53.04
57.79		1	1.2		
58.06		3	2		58.34
——	3960.43				
61.14		2	?		
69.25		2.3	—		69.44
72.66		2	—	Between two ⊙ lines.	
73.29		2.3	1.2		
74.87		3	2		74.74
75.48		1.2	—		
77.36		1.2	?		
78.80		3	2		
79.03		1.2	—	Diffuse.	
79.65		3	2		79.34
——	3986.90				
87.26		2	?	In the shading of a ⊙ line.	87.74
90.45		2	—	On one side of 90.52 (Fe).	90.84
91.69		2	—		
91.82		2	2		92.04
94.65		1.2	2		
95.45		4.5	2.3	⊙ double { 95.35 .45 Co.	95.33

Cobalt λ	R.	i Co	i ⊙	Remarks	Liveing and Dewar
3998.04		4	2.3		97.94
4011.08		1	1.2		
14.12		2	1		
——	4016.58				
19.47		2	1		
21.05		3.4	2.3		
23.54		1.2	2		
27.21		3	1.2		
——	4029.80				
35.73		3.4	?	Probably coinc. with ⊙ 35.75.	
40.76		1.2	1.2		
40.96		2	1		
45.53		4	2		
49.43		1.2	?		
4053.08		2.3	1.2		
54.08		2	—		
——	4055.70				
57.10		2	—		
57.36		2	1	Very sharp.	
58.36		2.3	2.3	Very sharp.	
58.75		2.3	1	Very sharp.	
66.52		3	1.2	Very sharp.	
68.72		3	1.2	Very sharp.	
69.70		1.2	—		
76.28		2.3	?	Very sharp.	
76.74		2	—		
77.55		2.3	1		
81.63		1.2	—		
82.76		2.3	1		
——	4083.77				
84.28		1.2	?		
85.74		1.2	1		
86.47		3.4	2		
92.55		4	2	⊙ double { 92.45 .56 Co.	
92.98		2	1		
93.20		2	1		
96.08		2	—	Divided from 96.12 (Fe).	
97.37		2	?		
4104.57		2	?		
04.89		2	1	Very sharp.	
09.83		1	—	Doubtful.	
10.21		2	?		
10.69		4	2.3		
18.92		4.5	3	⊙ double { 18.92 Co 19.02.	
21.47		4.5	3		
——	4121.97				
22.42		2	—		
39.58		2	—		
50.59		2	1.2		
——	4157.95				

Cobalt λ	R.	i Co	i ⊙	Remarks	Thalén
4158.58		2.3	1.2		
62.33		2.3	2	Double. $\Delta\lambda=0.09$.	
71.02		2	—	Not coincident with 71.07 (Fe).	
——	4185.06				
87.44		2	1		
90.87		3	1.2		
93.01		1	1		
98.01		1	—		
98.58		1.2	—		
4207.77		1.2	—		
10.26		1	?		
15.03		1	1		
——	4215.67				
25.28		1.2	2		
30.15		1	1.2		
——	(4233.40)			*	
34.18		2.3	1		
37.54		1.2	1		
38.63		1.2	1		
41.69		2	1		
42.06		2	?		
45.76		1.2	—	Diffuse.	
48.37		1.2	?		
52.47		3	1.2		
——	4254.50				
60.05		1.2	1		
63.92		1.2	—		
——	4267.96				
68.18		1.2	—		
68.59		2	—		
70.58		1.2	—		
76.25		2	1		
85.93		2.3	1.2	Very sharp.	
92.41		2	1.2	Diffuse.	
——	4293.25				
98.14		1.2	—	Diffuse.	
4303.36		2.3	2		
07.57		2	—		
09.54		2	2		
10.24		1	—		
——	4318.82				
20.53		1.2	1	Diffuse.	
31.38		2.3	—		
39.76		3	—	⊙ has $\begin{cases} 39.61 \\ .85\,\text{Cr.} \end{cases}$ No coincidence.	
40.39		1	—		
——	4343.39				
53.96		1.2	1		
57.05		2	1		
57.33		1	—		
59.60		1.2	1		
60.98		1.2	1.2		
61.20		1	—		

* The solar lines λ 4233.40, 4476.20 and 4530.95 are not in Rowland's list of standard lines, but they have been taken from his map of the solar spectrum.

Cobalt λ	R.	i Co	i ⊙	Remarks	Thalén
4362.11		1	—		
66.37		1.2	—		
71.27		3	?	Between two strong ⊙ lines.	
73.77		3	2		
74.66		1.2	2		
75.09		2.3	1.2		
75.70		2	?		
——	4376.10				
79.37		1.2	2.3	Perhaps Va. Neighboring Va lines do not occur.	
80.25		3	2	Diffuse.	
88.02		2	2		
91.70		3	1		
92.02		2.3	1		
95.99		2	2		
4402.85		2	1		
——	4407.85				
16.63		1.2	1		
17.55		3	?		
21.48		2.3	?	Sharp.	
31.78		2	—		
——	4435.85				
36.37		1.2	1		
38.05		1	1		
42.13		1	?		
45.21		2	—		
45.88		2.3	—		
——	4456.05				
67.04		3.4	2		
69.72		4	1		
71.70		3	?		
71.96		2	—		
——	(4476.20)				
77.36		1.2	—	Diffuse.	
78.45		3	1		
83.70		2.3	—	Diffuse.	
84.07		2.3	1	Sharp.	
84.65		2	—	Sharp.	
86.89		2	—	Sharp.	
90.46		1.2	—		
92.23		1.2	—		
——	4494.73				
94.92		2.3	—	Sharp.	
99.45		1	—		
4500.71		1	—		
——	4508.46				
14.33		2.3	2		
17.28		3.4	1.2		
19.42		2	—	Diffuse.	
24.88		1.2	1		
25.97		1.2	1	Coinc. ?	
26.94		1.2	—		
28.12		2.3	—		

Cobalt λ	R.	i Co	i ⊙	Remarks	Thalén
——	(4530.95)				
4531.14		5	2		31.45
34.18		4	3		
40.96		1.2	?	40.90 Cr.	
43.99		3.4	1		
45.42		2	—	Between two ⊙ lines.	
46.14		2.3	2		
47.06		1.2	?		
49.80		4	3	⊙ { 49.65 .80 } Ti has 49.79; probably divided.	
53.51		1.2	—		
——	4554.21				
62.11		1.2	—		
64.13		1.2	—		
64.35		2	—	Sharp.	
64.98		1.2	?		
65.74		4.5	?	Apparently displaced with reference to the ⊙ line 65.82.	
66.77		2.3	?		
70.18		3	?	Perhaps a ⊙ line.	
73.75		1	—		
75.12		1.2	—		
——	4578.73				
80.32		2.3	—		
81.76		5	?	⊙ strong double { 81.59. .69 Co?	81.75
87.08		1.2	—	Sharp.	
88.86		2	1	Sharp.	
94.75		4	1		
97.02		4	1		
4601.31		2	—		
07.46		2	1.2		
09.08		1.2	—		
——	4611.45				
12.57		1	—	Diffuse.	
14.18		2	?	⊙ has { 14.10 .35 } Co line appears to lie between these two.	
20.96		1.2	—		
22.83		1.2	—		
23.15		2.3	—		
24.70		1.2	—	Perhaps a ⊙ line.	
25.88		3	—		
29.05		2	—		
29.47		4.5	2.3	29.47 Ti.	
40.99		1.2	—		
——	4643.64				
43.92		2	—		
44.48		2.3	1		
45.34		1.2	1.2	45.36 Ti. Co line doubtful; i variable.	
51.28		1.2	—		
52.01		1.2	—		
53.93		1.2	—		

Cobalt λ	R.	i Co	i ⊙	Remarks	Thalén
4655.01		2	—		
57.56		2.3	1		
63.58		4	?		
68.04		1.2	—		
——	4668.30				
76.91		1.2	—		
77.46		1.2	—		
77.73		1.2	—		
——	4678.35				
80.62		1.2	—	Between two ⊙ lines. No coinc.	
82.53		4	1.2		
86.05		1.2	—		
88.68		1.2	—		
93.37		3.4	—		
97.19		1.2	1.2		
98.60		3	2		
99.35		2	—		
——	4703.99				
4704.57		1.2	—		
18.67		2.3	2		
21.61		1.2	—		
25.44		1	—		
——	4727.63				
27.95		1.2	—		
28.14		3	—		
32.25		1.2	—		
35.04		2.3	—		
37.95		2.3	—		
38.34		1	—		
42.40		1	—	Diffuse. Perhaps double.	
42.76		1	—		
46 31		2	?		
49.89		4.5	1		49.34
——	4754.23				
54.59		3	1		
56.93		2	?		
67.33		2.3	—		
68.26		3	1		
71 27		3.4	1.2		
76.49		3.4	1.2		
78.42		2.3	1.2	78.44 Ti.	
80.14		4	2		79.54
81.62		3	—		
82.76		1.2	—		
——	4783.60				
85.26		2.3	—		
93.03		4	1.2		92.54
96.00		2.3	—		
96.46		2	?		
97.93		1.2	—		
98.01		1.2	—		
——	4805.25				

Cobalt λ	R.	i Co	i ⊙	Remarks	Thalén
4813.67		4.5	1.2	}	14.40
14.16		3	?	}	
16.11		2	1		
18.13		1.2	1		
——	4824.32				
40.42		4.5	2	⊙ double { 40.42 Co. .50 Fe.	39.90
43.61		2.3	1.2		
55.40		1.2	?		
55.86		1	1.2		
——	4859.93				
62.29		1.2	—	Divided from 62.25 Mn.	
63.64		1.2	—		
68.05		5	1.2		67.90
69.59		2	1		
78.53		1.2	—		
80.43		1	—		
82.90		3	?		
87.19		2	1.2	Ni, Co ?	
——	4890.94				
97.36		2	—		
99.72		3	—		
——	4900.10				
4904.37		2.3	—		
07.30		1	—		
07.78		1	—		
08.68		1.2	?		
12.62		1.2	1		
——	4919.18				
20.47		2	—		
25.20		1.2	—		
28.48		3	1.2	Also Ti.	
33.08		1.2	—		
——	4934.25				
35 40		1	—		
36.61		1.2	—		
41.53		1	—		
42.56		1	—		
48.77		1.2	—		
53.37		2	1.2	Ni, Co ?	
——	4957.48				
59.89		1	—		
66.77		2.3	?		
67.72		1	1		
68.09		1.2	2	Diffuse.	
71.22		1 2	—		
72.16		2.3	—		
——	4973.27				
74.75		1.2	?		
80.15		2.3	—		
86.69		1.2	—		
88.15		2.3	?	Double, $\Delta\lambda = 0.16$. Setting on the middle.	

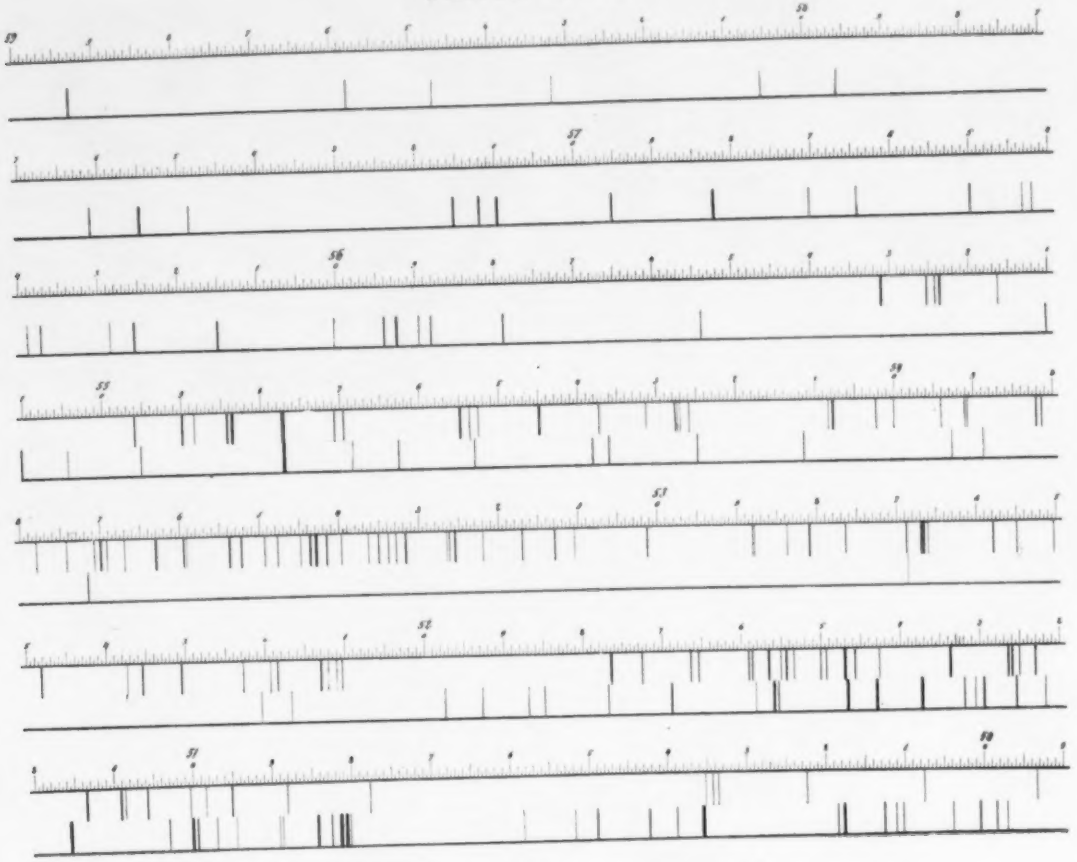
Cobalt λ	R.	i Co	i ⊙	Remarks.	Thalén
4993.27		1.2	1		
——	4994.32				
5007.49		1.2	2.3	Coinc. doubtful.	
——	5014.42				
22.37		1.2	2	A faint Fe line divided from Co.	
33.55		1	?		
34.24		1.2	?		
35.16		1	—		
——	5036.11				
77.64		1.2	?	Perhaps a ⊙ line.	
88.08		1.2	?	Perhaps a ⊙ line.	
95.18		2.3	1		
——	5097.18				
5100.30		1.2	—		
05.73		2	2	Int. of Co variable ; impurity ?	
08.55		1	1		
09.08		2.3	1		
13.41		2.3	1.2		
——	5115.56				
23.01		2.3	1		
24.99		1.2	?		
25.88		2.3	?		
26.37		2.3	2	Sharp.	
33.65		3	—	Sharp.	
——	5133.87				
42.65		1.2	2.3		
45.73		2	1.2	Diffuse.	
46.96		3	1	No ⊙ line on Rowland's map.	
49.32		1.2	1	Also Mn. No ⊙ line on Rowland's map.	
50.03		2	1		
——	5151.03				
53.43		1.2	1.2		
54.26		2.3	2		
55.04		1.2	—		
56.53		2.3	—		
58.61		2	—	Diffuse) between these lines there	
59.03		2	—	Diffuse) is a faint ⊙ line.	
65.32		2	1	No ⊙ line on Rowland's map.	
66.30		2	—		
72.49		2	?	Diffuse. In the shading of b_2.	
——	5173.91				
76.27		2.3	1	Very sharp.	
——	5188.95				
5210.28		1.2	—	Sharp.	
11.08		1	1		
12.87		2.3	1	Very sharp. ⊙ line distinct.	13.09
——	5217.56				
18.42		2	2		
19.28		1	—		
22.71		1.2	—		
30.38		2.3	1.2	Very sharp.	31.09
35.37		2.3	1	Very sharp.	35.49

Cobalt λ	R.	i Co	i ⊙	Remarks	Thalén
5237.32		1	—		
——	5242.66				
48.12		2.3	1	⊙ line excessively faint.	
50.21		2	—		
54.83		2	—		
57.81		2.3	1.2		
——	5261.88				
66.00		1.2	2		
66.51		3	1		
66.71		3	3.4		66.79
68.72		2.3	—	Very sharp. Between { 68.55 .80 } Fe	68.79
76.38		2.3	—	⊙ 76.20 = Cr.	
80.85		3	1.2		80.69
83.68		1.2	1.2	⊙ line is a companion to 83.80 (Fe).	
——	5283.80				
87.78		1.2	?		
88.02		1.2	?		
92.45		1	—		
5301.24		2.3	1.2	Very sharp.	
——	5307.55				
10.47		1.2	?	} Only traces of ⊙ lines.	
12.84		2.3	1	}	
16.96		2.3	2	⊙ line double { 16.75 .95 } The corona line.	
21.95		1.2	—		
25.44		2.3	1		
26.15		2	—		
26.49		1.2	—		
31.65		2.3	1.2	Very sharp.	
32.85		2	2		
——	5333.09				
33.85		2	1		
35.06		2	1.2	Co double.	
36.36		1.2	?		
37.56		1	?		
39.71		2	—		
41.53		2.3	—	Sharp.	
42.86		4	1.2		43.35
43.58		3	2		43.85
44.79		1.2	?		
47.68		2	—		
49.29		2	—		
52.22		2.3	1.2		52.45
53.69		3	1.2	⊙ double { 53.59 Fe. .69 Co.	53.65
59.16		1.2	1		
59.41		2.3	1		60.75
——	5361.81				
62.97		3	3	⊙ a close double. Coincidence probable with violet component.	63.75
66.97		1.2	—		

Cobalt λ	R.	i Co	i ⊙	Remarks	Thalén
5369.13		1.2	—		
69.79		3	1.2	Sharp. Ti has a line at 69.81.	69.25
70.60		1	1		
74.21		1	—		
77.99		1	1.2		
—	5379.78				
81.31		2	2		
81.99		2.3	1		
90.71		1.2	1.2		
91.01		1	—		
94.02		1	—		
—	5397.35				
5400.03		1.2	—		
02.24		2	1		
07.75		2.3	2	⊙ double { Violet component = Mn. / Red component = Co.	
08.37		1.2	—		
—	5415.42				
25.87		1.2	—		
27.01		1	—		
27.41		1	—		
27.59		1	—		
31.40		1.2	—		
—	5434.74				
37.25		2	1		
44.81		3.4	1		44.30
52.53		1.2	?		
53.61		1	—		53.30
54.79		3.4	1		
—	5455.76				
69.55		2	—		
70.73		2	—		
77.13		3	3		
—	5477.13				
77.37		2	—		
83.57		4	2		83.70
84.22		3	1		
88.38		1.2	1		
89.90		3	?		
95.94		2	—		
—	5497.73				
5516.29		1.2	—		
23.56		3	1		
24.24		1	1		
25.27		2.3	?		
—	5528.64				
31.06		3.4	1		

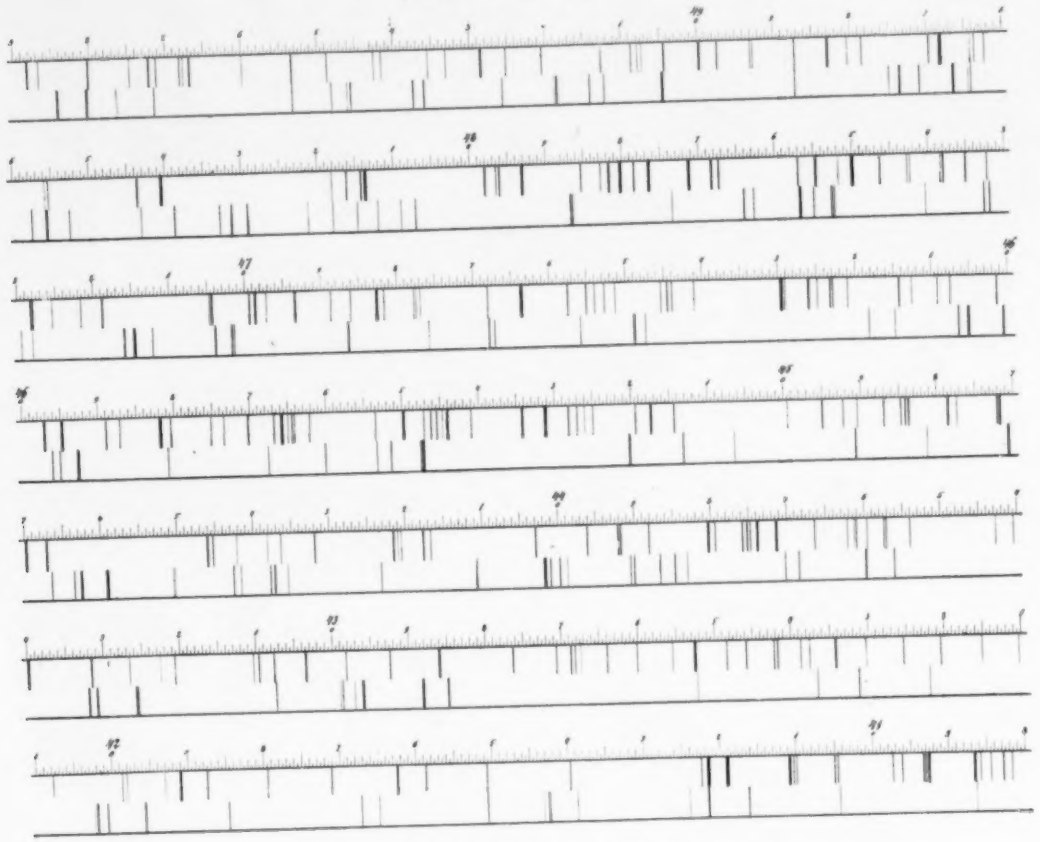
[*To be continued.*]

PLATE XVII.



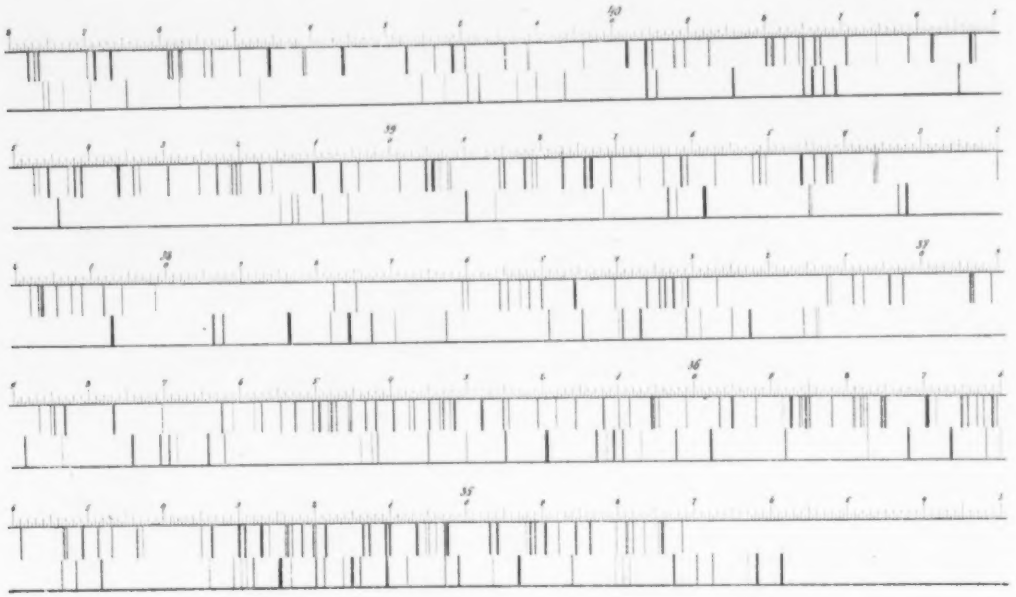
SPECTRA OF COBALT AND NICKEL.

PLATE XVIII.



SPECTRA OF COBALT AND NICKEL.

PLATE XIX.



SPECTRA OF COBALT AND NICKEL.

Minor Contributions and Notes.

ARMAND HIPPOLYTE LOUIS FIZEAU.

Armand Hippolyte Louis Fizeau died on the 18th of September last, having almost completed the seventy-seventh year of his life. His father, a distinguished physician, left him a fortune which enabled him to devote himself to the pursuit of science.

Fizeau's most notable achievement was the determination of the velocity of light in 1849: the first determination independent of astronomical methods, all of which involve a knowledge of the distance of the Sun from the Earth. It is true that his familiar toothed-wheel apparatus has proved less accurate than the more complicated revolving mirror method of Foucault in the hands of modern physicists, but even so lately as in 1874 Cornu preferred it in his very elaborate determination of this physical constant.

Another important question in physics with which Fizeau's name is connected is that of the influence of the motion of the medium through which light waves are moving. Fresnel had been led to the conclusion that a body carries with it in its motion only the excess of ether which it posesses above that of empty space. To test this conclusion Fizeau employed an interferential refractometer devised by himself. By its means he was enabled to pass two beams of light through two adjacent parallel tubes filled with water; then, after reflection, have each beam return by the path previously taken by the other. These two beams were combined at the focal plane of a telescope where the resulting interference bands could be observed. The water in the system of pipes was then set in motion so that one beam of light, both in going towards and returning from the mirror, was moving in the same direction as the water, while the other beam was in the contrary condition. The measured displacement of the interference bands was such as to confirm Fresnel's views.

Other important works were an investigation of the phenomena of interference of light waves when the difference of path differed very greatly, even to the extent of fifty thousand wave-lengths in some cases, and of the dependence of the refractive indices of solids on the tem-

perature. In the latter research Fizeau made the unexpected discovery that in many instances the index increases with rising temperature.

As Fizeau attained to an election into the French Academy in 1860 he has had the rare distinction of being a member for more than thirty-six years.

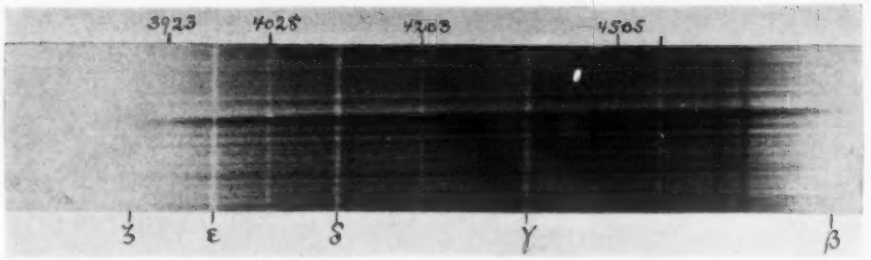
C. S. H.

FRANCOIS FELIX TISSERAND.

FRANCOIS FELIX TISSERAND was born on January 13, 1845, at Nuits-Saint-Georges, in the department of Côte-d'Or. After three creditable years of study in the Ecole Normale Supérieure he was appointed in 1866 assistant astronomer in the Paris Observatory, where Leverrier was then Director. During the succeeding seven years he conducted observational work in various departments of the Observatory, and in a discussion of the Moon's motion, gave evidence of the ability later more fully shown in his great treatise on Celestial Mechanics. In 1868 Tisserand observed the total eclipse of the Sun in Malacca, whither he was accompanied by MM. Stephan and Rayet. In 1873 he was appointed Director of the Toulouse Observatory, where he remained, superintending the execution of many important researches, until 1878, when he was recalled to Paris to occupy posts at the Bureau des Longitudes and the Sorbonne. His occupancy of the chair of Celestial Mechanics, first as associate and later as successor to Puiseux, dates from 1883.

At the death of Admiral Mouchez he was appointed Director of the Paris Observatory. The few years of his administration have been occupied with labors which will add both to his own reputation and to that of the great establishment which was in his care. The last volume of his well-known treatise on Celestial Mechanics was completed only a few months before his death. The important international undertaking of charting the heavens by photography, so successfully inaugurated by his predecessor, Admiral Mouchez, was carried forward by Tisserand with characteristic vigor. Admired by all, both for his scientific ability and his personal qualities, and rejoicing in the full development of his powers, he died suddenly in Paris on October 21, at the age of 51 years. His loss will be universally regretted.

PLATE XX.



SPECTRUM OF ζ PUPPIS.

HARVARD COLLEGE OBSERVATORY, CIRCULAR NO. 12.

STARS HAVING PECULIAR SPECTRA. NEW VARIABLE STARS IN CRUX AND CYGNUS.

A LIST of stars having peculiar spectra and found by Mrs. Fleming in her regular examination of the Draper Memorial photographs are given in the annexed table. The successive columns give the designation of the star, the approximate right ascension and declination for 1900, the catalogue magnitude, and a brief description of the character of the spectrum, followed by additional remarks when required.

Designation	R. A. 1900	Dec. 1900	Mag.	Description
	h. m.			
− 39° 3939	8 0.1	− 39° 43′	2.5	Peculiar. ζ Puppis. (Plate XX.)
Z.C. 11^{h}742	11 11.2	− 57 23	9	Type IV.
A.G.C. 15946	11 35.0	− 72 0	8.5	Type IV.
.....	12 26.9	− 57 1	..	Type III. Hydrogen lines bright. Variable.
− 36° 11341	17 7.0	− 37 0	9.1	Gaseous Nebula. Gal. long. 317° 12′. lat. − 0° 15′.
A.G.C. 22812	16 47.0	− 42 12	5.8	*Hβ* bright. ζ^{1} Scorpii.
A.G.C. 23694	17 24.1	− 49 47	2.9	*Hβ* bright. α Aræ.
+ 44° 3649	20 54.4	+ 44 24	7.9	Peculiar.
+ 44° 3679	20 58.9	+ 44 25	6.8	Peculiar.

The spectrum of the first of these stars is very remarkable and unlike any other as yet obtained. The continuous spectrum is traversed by three systems of lines. First, the hydrogen lines and the line K, which are dark, as in stars of the first type. Second, two bright bands or lines whose approximate wave-lengths are 4652 and 4698, which may be identical with the adjacent lines in spectra of the fifth type. Third, a series of lines whose approximate wave-lengths are 3814, 3857, 3923, 4028, 4203 and 4505, the last line being very faint. These six lines form a rhythmical series like that of hydrogen and apparently are due to some element not yet found in other stars or on the Earth. The formula of Balmer will not represent this series, but if we add a constant term and write $\lambda = 4650 \frac{m^2}{m^2 - 4} - 1032$, we obtain

for m equal to 10, 9, 8, 7, 6, and 5, the wave-lengths 3812, 3858, 3928, 4031, 4199 and 4504. The deviations from the observed wave-lengths have an average value of 3 ten-millionths of a millimeter, are systematic rather than accidental, and although small appear to be rather larger than might be expected from the errors of observation. A line of wave-length 5168 is indicated for $m = 4$, and, if present, could be observed visually, or photographed on a plate stained with erythrosin. The only other line found in the spectrum of this star has the wave-length 4620, and apparently does not belong to this series.

The fourth star in the table is a new variable in the constellation Crux. A comparison with eight adjacent catalogue stars gives its position for 1875, R. A. $= 12^h\ 25^m\ 27^s.5$, Dec. $= -56^\circ\ 53'\ 25''$. The period is about a year. The photographic magnitude, as derived from 57 plates, is 10.3 at maximum, and fainter than 13.2 at minimum.

The fifth of these objects is *N. G. C.* 6302, whose spectrum, on a photograph taken on July 9, 1896, is shown to contain the bright lines characteristic of gaseous nebulæ.

The presence of the bright hydrogen line in the sixth of these objects was found independently by Miss A. J. Cannon.

The last two objects in the table have similar spectra, containing two bright bands resembling, and perhaps identical with, those in the spectrum of ζ Puppis.

In addition to the above objects a star in the constellation Cygnus, whose approximate position for 1900 is R. A. $= 21^h\ 38^m.8$, Dec. $+ 43^\circ\ 8'$, has been found to be variable by Miss Louisa D. Wells. Its period appears to be about 40 days, and its photographic brightness varies from 7.2 to fainter than 11.2, an unusually large range for a variable having so short a period. Its position for 1900, as determined visually by Mr. O. C. Wendell, is R. A. $= 21^h\ 38^m\ 46^s.21$, Dec. $= + 43^\circ\ 7'\ 34''.8$.

EDWARD C. PICKERING.

November 2, 1896.

HARVARD COLLEGE OBSERVATORY, CIRCULAR NO. 13.

RELATIVE MOTION OF THE STARS IN THE LINE OF SIGHT.

THE determination of the motion of the stars in the line of sight by means of the spectroscope is one of the most important problems in

astronomy. The greatest, and almost the only, objection to the objective prism is that it has thus far failed to determine this quantity. Placing the prism in front of the objective has many advantages over the use of a slit spectroscope. Instead of photographing one star at a time, more than a thousand have, in many instances, been photographed upon a single plate. In fact, our only knowledge of the photographing spectra of the fainter stars is derived from plates obtained with an objective prism. The wave-lengths of the lines can also generally be determined equally well by either method, since in the spectrum of almost every star numerous lines are present whose wave-lengths have already been accurately determined in the solar spectrum. The wave-lengths of other lines can be better determined differentially from these than directly by a comparison spectrum. Nearly all of the Draper Memorial spectra have been photographed by means of objective prisms. Numerous unsuccessful attempts have been made here, ever since this work was undertaken, to determine with an objective prism the approach and recession of the stars (*Annals* XXVI., p. xx). Among other methods which have been tried may be mentioned the use of an absorbing medium like didymium, the variation in length of the spectra, and the use of a point of reference formed by throwing an auxiliary image of the star into the field by means of a small achromatic prism, or by reflecting prisms. Recently experiments have been made by comparing the corresponding lines in the spectra of different stars with their images taken on another plate without the prism and with the film reversed. A discussion of this method by the writer with Mr. Edward S. King has led to the method described below, which promises to determine accurately the relative motion of two or more stars in the line of sight if they are near enough together to be photographed upon the same plate. Let A and B be two such stars, A being at rest and B approaching with such a velocity that a given line in its spectrum is deviated by the amount d, and let a photograph be taken in such a position that the end of shorter wave-length of the spectrum of B is turned towards that of A. Than the distance between the images of the given line in the two spectra will be less by the amount d, than it would be if both stars were at rest. Now let another photograph be taken in which, by turning the prism 180°, the spectra are turned by the same amount, so that the end of greater wave-length of the spectrum of B is turned towards that of A. The distance between the two lines will then be increased by an equal amount. If two such

photographs are superposed and the images of the reference line in the spectra of A are made to coincide, its images in the spectra of B will deviate by $2d$. To apply this method, a photograph of a region a little east of the meridian is taken in the usual way. Then the telescope is reversed and a second photograph of the same region is taken on a plate with the film side away from the star, so that the photograph is taken through the glass. As both photographs are taken near the meridian the lines will be nearly perpendicular to the length of the spectrum, while, at a large hour angle, if the exposure is long, and the spectra narrow, the lines will cross them obliquely, owing to the differential refraction. Reversing the telescope turns the prisms, and with them the spectra exactly 180°. In making the examination the plates are placed film to film so that the spectra are side by side, and one is moved over the other by means of a micrometer screw. The corresponding lines in the two images of each star in turn are made to coincide, and the difference in the readings gives double the displacement of the line. An error in orienting the plates would affect the results when the stars compared are not in the same right ascension. This source of error may probably be made insensible in several ways, such as by marking a reference line on each plate, or by turning the prisms so that their edges are perpendicular to the line connecting the stars and moving the plate slowly by clock-work. Since the ends only of the lines are compared, narrow spectra may be used, and faint stars may therefore be measured. Experiments are now in progress with a cylindrical lens, by which it is expected that the accuracy of setting on lines in very narrow spectra can be still further increased.

Only preliminary tests of this method can be made at Cambridge at present, as our three best prisms are now in Peru. Two photographs of 101 and 102 Herculis were, however, taken on October 9, 1896, with a single prism, giving poor definition, but showed by inspection that the first of these stars was approaching more rapidly than the second. Measures by Mr. King of the lines $H\epsilon$ and $H\zeta$ indicated the relative velocities 87 and 94 kilometers a second respectively. These results are not corrected for the position of the prism and other sources of instrumental error. The probable error as indicated by the accordance of the individual settings is 5 kilometers in each case. An inspection of two photographs of the Pleiades shows that the relative motions of the seven brightest stars in the group, although perhaps

measurable is not appreciable to the eye, and probably does not exceed 30 kilometers a second.

The advantages of the above method are, first, the directness of the determination of the motion; second, that double the deviation is measured; and third, that as the ends of two similar lines are made to coincide, the accidental errors of measurement are much less than when each in turn is bisected by a spider line. Since each line in the spectrum may be used a large number of independent determinations may be obtained from one pair of plates. On the other hand, as it is only necessary that one line should be in focus, a visual telescope may be employed; that is, one uncorrected for the photographic rays. No corrections need be applied for the motion of the Sun in space or of the Earth in its orbit, since they will affect both stars equally.

EDWARD C. PICKERING.

November 4, 1896.

HARVARD COLLEGE OBSERVATORY, CIRCULAR NO. 14.

A NEW SPECTROSCOPIC BINARY IN PUPPIS.

AN examination of the Draper Memorial photographs taken at the Arequipa Station shows that the star Lacaille 3105, *Argentine General Catalogue* 10534, is a spectroscopic binary. The approximate position of this star for 1900 is R. A. $=7^h\ 55.3$, Dec. $=-48°\ 58'$. Its photometric magnitude is 4.50. The lines in its spectrum were first noticed to be double and its binary character discovered by the writer in February 1895. Professor Bailey was notified and accordingly secured additional photographs and confirmed the binary character of this star. As in the case of μ^1 Scorpii one component is brighter than the other. A discussion of all the photographs of its spectrum here and at Arequipa gives the mean period $3^d\ 2^h\ 46^m$. The times of inferior conjunction can be represented by the formula $J.\ D.\ 2412777.16 + 3.115\ E$. At these times the lines are single, for the next thirty-seven hours the lines are double, the fainter component of each having a greater wave-length than the brighter component, and being, therefore, towards the red end of the spectrum. The lines then again become single, and after that, for the remainder of the period are again double, the fainter components having shorter wave-lengths, and being, therefore, towards the violet end of the spectrum.

This is the fourth spectroscopic binary of this class in which both components are bright, the others being ζ Ursa Majoris, β Aurigae and μ^1 Scorpii.

EDWARD C. PICKERING.

November 17, 1896.

ERRATA.

In this JOURNAL, **4**, 176, Rowland's and Michelson's wave-lengths of the cadmium lines should have been given as follows:

Rowland's values of the wave-length of the cadmium lines, *reduced to 20° centigrade*, are 6438.680, 5086.001, 4800.097.

Michelson's values of the wave-length of the cadmium lines, *reduced to 20° centigrade*, are 6438.472, 5085.824, 4799.9107.

J. F. MOHLER.

Recent Publications.

A LIST of the titles of recent publications on astrophysical and allied subjects will be printed in each number of the ASTROPHYSICAL JOURNAL. In order that these bibliographies may be as complete as possible, authors are requested to send copies of their papers to both Editors. For convenience of reference, the titles are classified in thirteen sections.

1. THE SUN.

ABNEY, W. DEW. and T. E. THORPE. The Determination of the Photometric Intensity of the Coronal Light during the Solar Eclipse of 16th April, 1893. Proc. R. Soc. **60**, 15–17, 1896; Phil. Trans., Part I. 1896.

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CORNU, A. M. Fizeau. C. R. **123**, 471–472, 1896.

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NOTICE.

The scope of THE ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

It is intended to publish in each number a bibliography of astrophysics, in which will be found the titles of recently published astrophysical and spectroscopic papers. In order that this list may be as complete as possible, and that current work in astrophysics may receive appropriate notice in other departments of the JOURNAL, authors are requested to send copies of all papers on these and closely allied subjects to both Editors.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. If a request is sent *with the manuscript* twenty-five reprint copies of each paper, bound in covers, will be furnished free of charge to the author. Additional copies may be obtained at cost price. No reprints can be sent unless a request for them is received before the JOURNAL goes to press.

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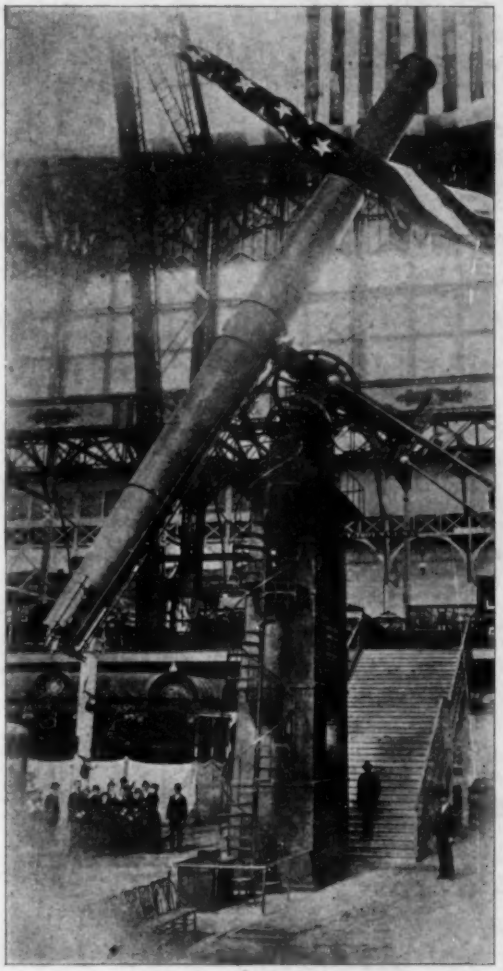

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